

PHYSICS

Energy Flow from
Earth's Systems

**How can we
design more
reliable systems
to meet our
communities'
energy needs?**



HIGH SCHOOL SCIENCE



TEACHER EDITION

How can we design more reliable systems to meet our communities' energy needs?

Energy Flow from Earth's Systems: Electricity

OpenSciEd Unit P.1





Version 1.0 - Copyright © 2023 OpenSciEd

Licensed under the Creative Commons NonCommercial Attribution 4.0 International License (CC BY-NC 4.0). The OpenSciEd name and logo are not subject to the Creative Commons license and may not be used without the prior and express written consent of OpenSciEd. The OpenSciEd high school classroom curriculum materials are licensed under the CC-BY-NC 4.0 license.

Although the CC-BY-NC License is limited to non-commercial uses, commercial uses of our classroom curriculum materials are still encouraged and will now be available pursuant to our License for Commercial use of Curriculum Materials, which supplements the CC-BY-NC License. Commercial uses of a certain scale may require the payment of fees to OpenSciEd to support the development and maintenance of the OpenSciEd assets.

You may copy, distribute and modify the OpenSciEd curriculum materials for Non-Commercial purposes pursuant to the terms and conditions of the CC-BY-NC license, which requires, in part, that you provide attribution to OpenSciEd, and, for online uses, provide a prominent hypertext link back to OpenSciEd's website located at www.opensciEd.org. "Non-Commercial" shall have the meaning given to such term in the CC-BY-NC License; subject to compliance with its terms, such license would permit use for academic purposes of the Curriculum Materials obtained through publicly available means, so long as such use is not commercial in nature. The above is a short summary of OpenSciEd's interpretation of the CC-BY-NC License, and is not a substitute for the full text of the CC-BY-NC.

This curriculum includes images that are public domain, openly licensed, or used by explicit agreement with their owners. See the attribution information with each image for ownership details and any restrictions on its use. Unless otherwise noted in the image attribution information, all images are licensed for distribution under the terms of the Creative Commons Attribution License (CC BY 4.0) by OpenSciEd or by their respective owners, or they are in the public domain.

The development of this material was supported by the Bill & Melinda Gates Foundation, Carnegie Corporation of New York, Walton Family Foundation, and William and Flora Hewlett Foundation.

To download the handouts, slides, and other unit resources, visit OpenSciEd.org and complete the free registration.



This work is licensed under a Creative Commons NonCommercial Attribution 4.0 International License along with OpenSciEd's License for Commercial Use of Curriculum Materials v1.0.

Unit Development Team

Zoë Buck Bracey, Unit Lead, BSCS Science Learning
Jairo Botero Espinosa, Consultant Expert
Juan Pablo Carvallo, Consultant Expert
Joseph Hardcastle, Writer, BSCS Science Learning
Joseph Kremer, Writer, Denver Public Schools
Michael Novak, Writer, Northwestern University
Diego Rojas-Perilla, Writer, BSCS Science Learning
Nicole Vick, Writer, Northwestern University

Production Team

Madison Hammer, Production Manager, University of Colorado Boulder
Kate Herman, Copy Editor, Independent Consultant
Erin Howe, Project Manager, University of Colorado Boulder
Whitney Mills, BSCS Science Learning
Tyler Morris-Rains, BSCS Science Learning
Jamie Deutch Noll, BSCS Science Learning
Laura Zeller, BSCS Science Learning

OpenSciEd

James Ryan, Executive Director
Sarah Delaney, Senior Director
Matt Krehbiel, Senior Director

High School Science Developers Consortium

inquiryHub, University of Colorado Boulder
William Penuel, Director of HS Development Consortium
Tamara Sumner, Co-Director
Kate Henson, Co-Director, Course Coordination Lead, Biology Course Lead
Dawn Novak, Professional Learning Lead
Kristin Rademaker, Professional Learning Specialist
Ann Rivet, Advisor on ESS Integration

BSCS Science Learning

Daniel C. Edelson, Director
Zoë Buck Bracey, Associate Director, Physics Course Lead
Kevin Cherbow, Professional Learning Specialist

Northwestern University

Brian Reiser, Director
Michael Novak, Associate Director
Nicole Vick, Chemistry Course Lead
Samantha Pinter, Professional Learning Specialist

Charles A. Dana Center, The University of Texas at Austin

Shelly LeDoux, Director
Carol Pazera, Associate Director, Evaluation
Molly Ewing, Professional Learning Specialist

Denver Public Schools

Douglas Watkins, District Partner Director

State Steering Committee

California

Jill Grace
Susheela Valdez

Iowa

Christopher Like
Jason Martin-Hiner
Tami Plein

Louisiana

Tana Luther
Breigh Rhodes
John Underwood

Massachusetts

Casandra Gonzalez
Erin Hashimoto-Martell
Nicole Scola

Michigan

Mary Starr
Michael Tanoff

New Jersey

Michael Heinz
Ivory Williams

New Mexico

Shafiq Chaudhary
Yanira Vázquez

Oklahoma

Heather Johnston
Paige Kelpine

Rhode Island

Erin Escher
Carolyn Higgins
Phyllis Lynch

Washington

Johanna Brown
Ellen Ebert

Field Test Teachers

California

Christopher Alvarado
Brian Hamilton
Aschli Hicks
Rachel Kagan
Jonathan Kamp
Tali Lerner*
Adrian Melendez
Terrence Mitchell
Deanna Nelson
Joey Notaro
Kathi Nugal
Doug Reimers
Steve Sue
Satoshi Suga
Greg Trautman
Eric York

Iowa

Marci Denney
Nicole Dobson
Katherine Eastin
Joy Jones
Jennifer Wells*
Lauren Winter

Massachusetts

Robert Blackler*
Jonathan Clough
Matthew Kelly
Tuula Laskorski
Savannah Lodge-Scharff
Brenda Marrero
Oliver McNeely
Jo Persad
Corey Sleep
Julie Tran
Katharine Waldron

Michigan

Laura Allen
Jason Austermann
Lara Beydoun
William Carey
Kerry Gargaro
Christina Giovanni
Emily Jones
John Mackson
Casey McDonnell
Andrew Mikolajczak
Nate Nickolai
Bryant Sebastian

Louisiana

David Bennett
Katie Leopard

New Jersey

Shima Alabdullah
Mariel Kolker
Jesse Kosior
Patricia Morris
Jennifer Tan

New Mexico

David Cain
Robert Cushman
Katherine Dockery
Umedi Rasulzoda

Rhode Island

Michael Engelbrecht
Jo-Ann Mangiarelli
Douglas McGunagle
Jamie Puleo

Washington

Sacha Buller
Myron (Ted) Flint
Heather Greek
Adrien Kimbrough
Danielle Kuchler
Zach Pope
Don Pringle*
Jamie Sproul
Theodore White
Matthew Winkler
Emily Wise

Pilot Teachers

Denver Public Schools

Kathryn Fleegal
Madelyn Percy
Risa Wolff
Mariajose Ytterberg

Student

Contributors

Denver Public Schools

Lily M.

San Diego USD

Reese Chell
Kai McIntyre
Vanessa Neumeyer
Cole Schoene

*Special thanks to teachers who participated in the co-revision process

TABLE OF CONTENTS

Unit P.1 How can we design more reliable systems to meet our communities' energy needs?

Unit Overview	1
Unit Storyline	3
Teacher Background Knowledge	9
Home Communication	26
Lesson 1: What can we learn from a blackout in Texas about producing reliable energy for our communities?	29
Lesson 2: What structures in the system enable energy transfer from one source to multiple devices, buildings, and neighborhoods?	47
Lesson 3: Could the blackouts in Texas have been caused by a broken or short-circuited circuit?	73
Lesson 4: What makes an energy source reliable?	93
Lesson 5: Where does electrical energy come from?	105
Lesson 6: How does energy transfer in wires?	133
Lesson 7: What could have caused the disparities we saw in the blackouts in Texas?	153
Lesson 8: Why do design solutions affect some people differently than others?	171
Lesson 9: How can energy storage make our systems more reliable during an energy crisis?	185
Lesson 10: What decisions do we need to make to design more reliable systems to meet our community's energy needs?	197
Lesson 11: What have we figured out, and what can we carry forward?	209
Unit P.1 Teacher Reference Materials	225
Unit P.1 Lesson-Specific Teacher Materials	239

UNIT OVERVIEW

How can we design more reliable systems to meet our communities' energy needs?

This unit is anchored by the Texas power crisis of February 2021. Students read articles and wonder about the complex social, environmental, and physical realities that led to such a crisis. In Lesson Set 1 (Lessons 1-8), students figure out how energy transfers between systems from a generator to our communities, and what makes an energy source reliable. By the end of this lesson set, students can model and explain what happened in Texas at multiple scales, from the electrons in the wires to the power companies making difficult decisions to maintain stability. In the second lesson set (Lessons 9-11), students consider engineering tradeoffs, criteria, and constraints inherent in making decisions about our energy systems, and apply them in a culminating task: design a reliable energy solution that meets our communities' needs, as articulated by interviews with friends and family members. The task is designed to give students the tools to speak up in their local and global community for a better energy future, one that aligns with their own values, and those of their families.

Throughout the unit, students will do the following:

- Develop and use both physical and conceptual models related to our energy transfer systems, including a small wired city that is powered by a homemade generator, energy transfer diagrams that include field interactions, and a computational spreadsheet model to test out design solutions against criteria for success.
- Use simulations to model and understand particle and field interaction in and around a wire, and to investigate the impact of changing certain variables on energy transfer through the wire.
- Analyze, synthesize, and interpret data about what happened in Texas in February 2021, highlighting an imbalance in energy inputs and outputs, and using the correlation coefficient to disprove a hypothesis.
- Obtain and communicate information about energy flow, electricity, engineering, and power outages from a variety of different kinds of texts.
- Define a design problem, and develop design solutions related to the use of Earth's resources for electricity production and energy storage based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Building Toward NGSS Performance Expectations

HS-ESS3-2:

Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* [

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, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

HS-ETS1-4:

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

HS-PS2-5:

Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

HS-PS3-1:

Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

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 positions 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.*

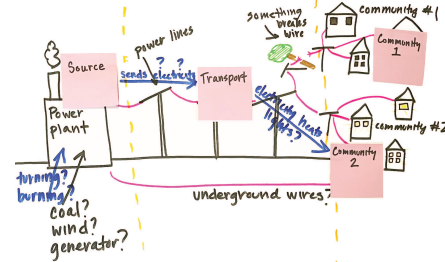
UNIT STORYLINE

Unit Question: How can we design more reliable systems to meet our communities' energy needs?

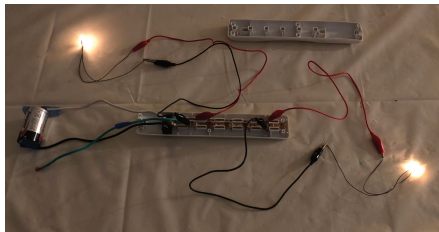
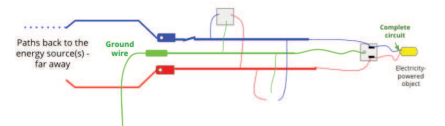
How students will engage with each of the phenomena



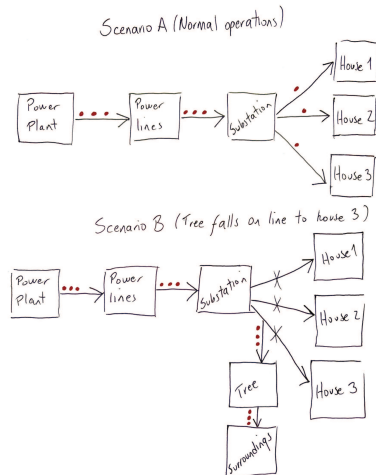
Lesson Set 1: How does electricity transfer through systems to power communities, and what causes instability in these systems?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 3 days What can we learn from a blackout in Texas about producing reliable energy for our communities? Anchoring Phenomenon 	 <i>A winter storm in Texas in February 2021 led to devastating widespread blackouts throughout the state.</i>	We explore a new phenomenon by jigsawing a series of articles about widespread blackouts in Texas, and by drawing on the experiences of our friends and family. We make an initial consensus model of what happens to our electricity production system when it is stable and during a blackout. We develop questions for our DQB and brainstorm initial ideas about ways we could design more reliable systems to meet our communities' energy needs. We figure out: There are several components that we agree are important for understanding how energy transfers to power our communities when the system is stable and during a blackout.	

↓ **Navigation to Next Lesson:** We decide to document the electricity infrastructure in our homes and communities to look for patterns that could help us understand how the system works and identify important design constraints.

LESSON 2 Lesson Set 1 2 days What structures in the system enable energy transfer from one source to multiple devices, buildings, and neighborhoods? Investigation 	 <i>In a power strip, there are three pieces of metal that are each connected to three wires within the plug. Similar structures are found within a house, and even within electrical grid substations.</i>	We compare photos of structures that provide electricity in our buildings. We dissect a power strip as an analog for what's behind the walls of buildings, and we connect a battery and a couple of small devices. We read about the function of ground wires and circuit breakers. We develop a model to show how systems transfer electrical energy. We figure out: - Energy will transfer from an electrical energy source to an electronic device when a complete circuit is formed, but will not transfer when there is a break in any of those paths. - If a short circuit is created, most of the energy will not transfer through the other circuits. Such small changes in one part of the energy distribution system could cause blackouts across multiple buildings or neighborhoods.	
---	--	--	---

↓ **Navigation to Next Lesson:** We are thinking that short circuits or broken circuits could have been a cause for the patterns of blackouts we saw in Texas, so we want to investigate this possibility.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 Lesson Set 1 3 days Could the blackouts in Texas have been caused by a broken or short-circuited circuit? Investigation 	 <i>Electricity demand forecast data did not match electricity production in Texas during February 2021.</i>	We read about an energy crisis that began in Ohio, and a strategy used by engineers to prevent short and broken circuits in power lines. We use the <i>Engineering Design Tracker</i> to keep track of our ideas. We develop a new representation to model energy transferred in various parts of the system. We analyze electricity demand and supply data in Texas and use this to brainstorm ideas of where to go next. We figure out: - Engineering constraints can affect the implementation of a possible solution. - The production of electrical energy must match the demand for electrical energy. - The cold temperatures during the Texas blackout caused a spike in energy demand, which was accompanied by a drop in the supply of electrical energy.	 <i>Scenario A (Normal operations)</i> <i>Scenario B (Tree falls on line to house 3)</i> <i>Date Source: US Energy Information Administration</i>

↓ **Navigation to Next Lesson:** We saw a mismatch between the amount of energy generated and the amount of energy demanded by communities in Texas, which led us to wonder what could have caused the observed drop in the supply..

LESSON 4

Lesson Set 1

2 days

What makes an energy source reliable?

Investigation





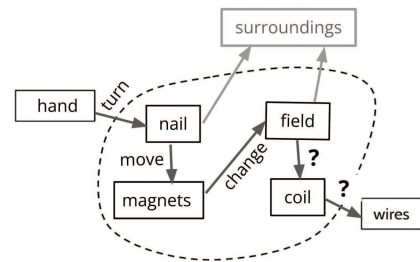
Descriptive and graphic data on a variety of energy sources reveal puzzling inconsistencies in each energy source's reliability during the blackout.

We use informational cards and several data representations from the 2021 Texas energy crisis to seek additional information about specific sources of energy to help us figure out which source might be responsible for the drop in supply we discovered in Lesson 3. We use a new tool called a *Decisions Matrix* to keep track of how well each source meets criteria we think are important. We figure out:

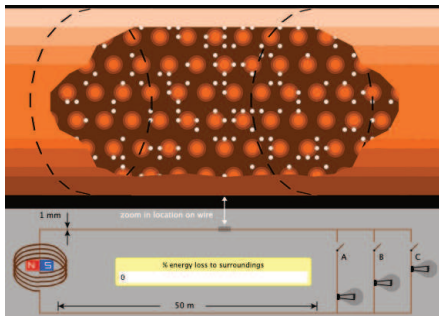
- The energy used to create electricity in a power plant comes from Earth's systems.
- Making decisions about complex societal issues like energy production requires defining criteria for success that might not be straightforward or easy to quantify.

Energy Source	Energy Sources Im			
	Criterion #1	Criterion #2	Criterion #3	Criterion #4
	High Reliability	High Renewability	High Efficiency	
Wind	*	****	**	
Solar	*	****	*	
Biomass	***	***	**	
Coal	****	*	**	
Natural Gas	****	**	***	
Nuclear	****	***	***	
Hydroelectric	***	***	****	
Geothermal	***	****	**	

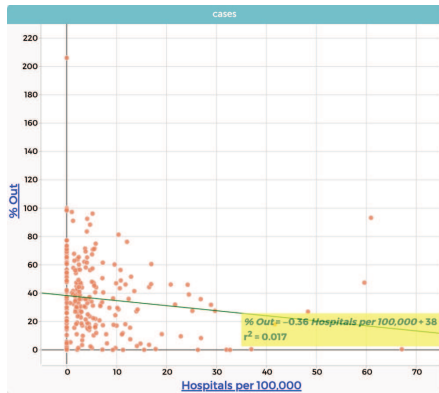
↓ **Navigation to Next Lesson:** Since we are now wondering why some energy sources are more reliable than others (or efficient, powerful, dispatchable), we want to compare how the electricity from these different sources is produced.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 5 Lesson Set 1 3 days Where does electrical energy come from? Investigation 	 <i>A light connected to generator glows and nearby compass needles change direction when either the magnet or wires in a generator moves.</i>	We use diagrams of wind and natural gas power plants to figure out how power plants transfer energy into wires. We dissect a generator and then reverse engineer it. We use compasses to investigate energy transfer between the magnet and wire, and model the energy transfer through fields inside our generators. We figure out: - Many power plants have generators, which are loops of copper wire and powerful magnets. - Matter changes and/or motion can cause energy transfer through contact (and vice-versa). - The motion of a magnet can generate changing fields, which can cause energy transfer at a distance (and vice-versa). - When moving matter (e.g., pushing wind or steam) moves the magnets inside a generator, that can cause energy transfer into wires through changing fields.	

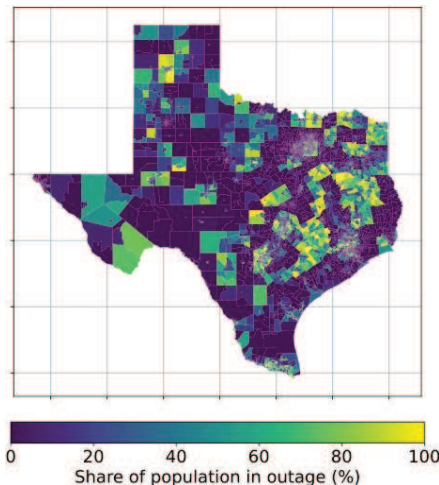
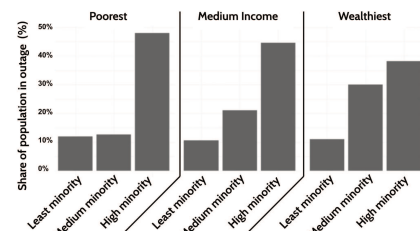
↓ **Navigation to Next Lesson:** Though we have a model for how generators transfer energy to wires, we don't know what is happening inside the wires when they transfer energy (electricity) to our communities.

LESSON 6 Lesson Set 1 3 days How does energy transfer in wires? Investigation 	 <i>A simulation of electrons in a wire shows their motion with various circuit configurations and power sources, and it provides a measure of energy and current in various parts of the system.</i>	We read about electric and magnetic fields to help us model energy transfer involving fields more closely, focusing on transfers inside a wire. Using a simulation, we explore how various characteristics of an electrical system could influence the transfer of electrical energy, as well as their relation to energy loss, and check our results using classroom equipment. We figure out: - Electric and magnetic fields change when energy transfers into or out of them. - Electric fields can push electrons. "Electrical energy" is the energy of the movement of electrons transferring through pushes from fields. - A turbine transfers energy through electric and magnetic fields to the electrons in a wire, causing them to slosh back and forth continuously. - Electrons cause the atoms of the wire material to heat up, transferring energy from the system to the surroundings as "heat".	<u>Wire Sim Results</u> ● <i>As ... increases, ... decreases.</i> ● <i>As ... increases, ... increases.</i> ● <i>As ... increases, ... doesn't change much.</i>
--	--	---	--

↓ **Navigation to Next Lesson:** Since we figured out that cold weather does not affect energy loss from wires much, we think we can model in greater detail how insufficient supply can account for the affects on people in Texas.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 7 Lesson Set 1 2 days What could have caused the disparities we saw in the blackouts in Texas? Problematizing 	 <i>A data set shows disparities between counties impacted by the energy crisis in Texas that is not well explained by our model.</i>	We develop a model showing how insufficient supply entering the system could lead to buildings losing power during a crisis. We test our models using Electric City, and we notice that to keep the lights on in one building, we need to cut power to others. We use data to test for correlations with county-level factors, and we consider limitations on this analysis. We figure out: - Power companies in Texas probably had to make decisions about who lost power in some places in order to keep the lights on in others. - There is no one factor that explains why some counties in Texas lost power and others did not.	 <i>Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium., Data Source: Mills & Gorman (1997)</i>

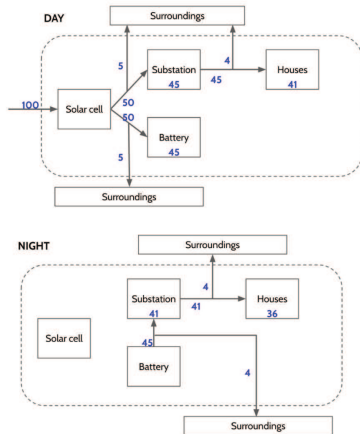
⬇ Navigation to Next Lesson: We figured out limitations associated with analyzing data grouped by counties because the scale of a single county is large. We wonder what those data look like at a smaller scale.

LESSON 8 Lesson Set 1 2 days Why do design solutions affect some people differently than others? Putting Pieces Together 	 <i>Scientists looking at satellite data uncovered patterns in the Texas power outages that we could not discern at a county-level scale.</i>	We listen to (and read the transcript of) a podcast featuring a scientist whose research group used satellite data to investigate patterns in who lost power in Texas. We read about two fictionalized families in Texas and consider how existing disparities can make the impact of a power outage inequitable across communities. We figure out: - An imbalance of energy supply and demand was the primary cause of the blackouts in Texas in February 2021. - There are design solutions for avoiding this in the future, but they come with tradeoffs. - Across Texas, what neighborhood people lived in made an impact on whether they lost power. - Power outages have an inequitable impact on people in communities where there are existing disparities. - Throughout Texas, power companies made decisions to keep the power on in neighborhoods with “essential” buildings.	 <i>Zeal Shah, Feng Chi Hsu, Jay Taneja, JP Carvallo</i>
---	--	---	---

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
-----------------	-----------------------------	---------------------------	---------------------

↓ **Navigation to Next Lesson:** We figure out tradeoffs, related to generating power, around which sources we use. We leave with a home learning about tradeoffs associated with various energy sources.

Lesson Set 2: What design solutions could improve the electricity systems in our communities?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 9 Lesson Set 2 2 days How can energy storage make our systems more reliable during an energy crisis? Investigation 	 <i>Batteries are not currently widely used in power grids.</i>	We develop and revise energy transfer models to represent how batteries can make electric grid systems more reliable. We quantify how much energy was needed to prevent the energy crisis in Texas 2021. We use data from energy storage solutions to calculate the number of batteries needed and the costs associated with adding these batteries to the system. We wonder about the costs from design solutions that are not financial. We figure out: - All forms of energy production and other resource extraction have economic, social, environmental, and geopolitical costs and risks as well as benefits that we will need to consider when making decisions about our own communities. - Design solutions that store excess energy can prevent an energy crisis by bridging the gap between energy demand and supply. - Energy storage systems can make an electric grid more reliable by providing power when the energy supply drops.	

↓ **Navigation to Next Lesson:** We wonder what additional, non-financial costs might be associated with design solutions.

LESSON 10

Lesson Set 2

3 days

What decisions do we need to make to design more reliable systems to meet our community's energy needs?

Investigation





There are multiple criteria, constraints, and tradeoffs to consider in making engineering decisions, and the interested parties in our communities don't always agree.

We read about tradeoffs associated with various energy sources. We create a class Consensus Decisions Matrix that represents the criteria we agree are important when making decisions. We read quotes from interested parties, and develop and carry out an interview protocol to capture the values of people in our community. We begin developing a plan for improving electricity infrastructure in our community. We figure out:

- When developing design solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
- Input from interested parties can be a great tool for determining the values that should guide how we address tradeoffs.

Ranking	Criterion* & Reason - Interested Party #1 (Mother)	Criterion* & Reason - Interested Party #2 (Grandmother)
Highest Priority	Cost: I have three kids, and I belong to the middle income bracket, which means the cost of living is super high. If the electricity bill were to be cheaper, that would be a big help.	Environmental impact: I have seen the impact we are having in the environment. My biggest priority is to ensure we do not continue damaging our planet.
Second highest	Safety: A power plant can affect our town and our environment, especially if it is going to be close to where I live. I don't want something polluting the air of the water that my family drinks.	Social impact: Some communities living close to where the power plants are built might be more affected. I don't want energy generation to affect other communities.
Second lowest	Environment: I want to have a planet for my kids and my grandchildren.	Cost: Electricity is expensive, but I can afford it.
Lowest priority	Aesthetics: I want my region to look nice, but it is not a big priority. If it is going to be close to my place and affect my property value, then I would care more.	Reliability: I know the fluctuation of energy in this region is not significant, so that is not my main concern.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
-----------------	-----------------------------	---------------------------	---------------------

↓ **Navigation to Next Lesson:** While we have identified tradeoffs associated with various energy sources, and criteria from various interested parties, we haven't yet produced designs for improving the electricity infrastructure in our community that responds to interested parties' opinions that address these tradeoffs.

LESSON 11

Lesson Set 2

3 days

What have we figured out, and what can we carry forward?

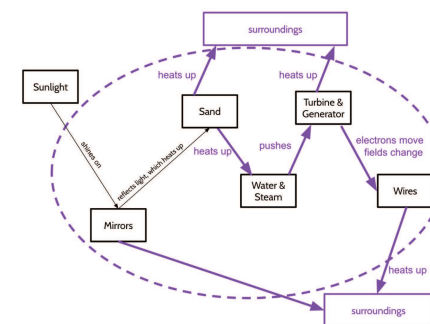
Putting Pieces Together



Complex global challenges manifest in our communities. Developing solutions will require science practices and creative design thinking.

We learn about the Energy Grid Calculator, a computational model that we use to measure the success of our solutions against a variety of criteria. We describe our design solution to our classmates, and we give each other feedback that we use to refine our designs. We return to the DQB and celebrate our progress in light of all the questions we can answer. We work through an assessment task in which we explain energy transfer in a solar sand power plant and use data to evaluate the feasibility of using this technology to provide reliable power to a community. We figure out:

- Science learning is about asking questions, defining problems, and gathering evidence to answer those questions and address those problems.



↓ **Navigation to Next Lesson:** This is the last lesson in the unit.

LESSONS 1-11

28 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices when conducting hands-on science investigations and demonstrations, whether in an instructional space (traditional laboratory or classroom) or in the field. To this end, teachers must be aware of any school or district safety policies, legal safety standards, and better professional safety practices that are applicable to the activities being undertaken.

Science safety practices in instructional spaces require engineering controls and personal protective equipment (e.g., sanitized safety goggles or safety glasses with side shields as appropriate, non-latex aprons and gloves, eyewash/shower station, fume hood, appropriate ventilation, and fire extinguishers). **Science investigations should always be directly supervised by qualified adults, who should review safety procedures annually, and also before initiating any hands-on activities or demonstrations.** Prior to each investigation, students should be reminded of the specific safety procedures they must follow. Each lesson within the OpenSciEd units includes teacher guidelines for applicable safety procedures for setting up and running an investigation, as well as disassembling, disposing of, and storing materials.

Prior to the first investigation of the year, a safety acknowledgement form for students and parents/guardians should be provided and signed. You can access a model safety acknowledgement form for high school activities here: <https://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.pdf>

Disclaimer: The safety precautions provided for each activity are based in part on use of the specifically recommended materials and instructions, as well as legal safety standards and better professional safety practices. Be aware that selecting alternative materials or procedures for these activities may affect the activity's level of safety, and is therefore at the user's own risk.

Please follow these lab safety recommendations for any science investigation:

1. Wear sanitized safety goggles (specifically, indirectly vented chemical splash goggles) or safety glasses with side shields, as appropriate, a non-latex apron, and non-latex gloves during the set-up, hands-on investigation, and take-down segments of the activity.
2. Safety goggles are required when working with liquid biological or chemical hazards (e.g., microbes, acids, bases, etc.). Safety glasses with side shields or safety goggles may be used when working with physical hazards (sharps, springs, glass, projectiles, etc.).
3. Immediately wipe up any spilled liquid (e.g., water) and/or granules on the floor, as this is a slip-and-fall hazard.
4. Follow your *Teacher Guide* for instructions on disassembling and storing materials and disposing of waste materials.
5. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
6. Wash your hands with soap and water immediately after completing the activity.
7. Never eat any food items used in a lab activity.
8. Never taste any substance or chemical in the lab.
9. Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
10. Use caution when working with glassware, which can shatter if dropped and cut skin.
11. Use caution when using sharp [tools/materials], which can cut or puncture skin.
12. Never pour chemicals, either used or unused, back into their original container. Dispose of chemicals according to your teacher's instructions.
13. If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
14. If you get a chemical in your eye, use an eyewash station immediately.
15. Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
16. When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
17. Projective trajectory zones must be well defined and free of any obstacles. No participant is to be in the zone during operation of the projectile..
18. Make sure the ventilation system meets the needs relative to removal of flammable vapors produced. Also make sure there are no active flames or sparks in the work zone.



Specific safety precautions are called out within the lesson using this icon and a call-out box.

Where does this unit fall within the OpenSciEd Scope and Sequence?

This unit, *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, is the first in the OpenSciEd High School Physics course sequence. It is designed to transition students into high school level physics ideas and practices in a relevant context grounded in real-world decision-making. Although students have been asking questions, modeling systems, designing solutions, and engaging in argument from evidence throughout K-12, this may be their first time using these practices the way physicists do: to figure out how and why matter moves and changes, using the lens of energy transfer. Students develop ideas around energy transfer and conservation in the context of charged particles (electrons) colliding with other electrons (electricity) to transfer energy across great distances. This unit builds a foundation for understanding energy transfer and conservation in a physics context that students will carry forward into the rest of the course; however, it does not yet focus on forces as a way to model interactions.

In the second unit of the physics course, *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*, a sudden rip in Earth's crust motivates the need to consider forces to explain our observations. In the third unit, *OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)*, students develop a more robust understanding of forces as vectors and use conservation of momentum to make predictions about the outcomes of collisions. In the fourth unit, *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*, students expand their model of forces to include the force of gravity at great distances, using ideas about fields developed in the first unit to understand the relationships between gravity and energy transfer. In the fifth unit, *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*, students use energy transfer, electromagnetism, wave mechanics, and forces at a distance to explain how food heats up in a microwave and how this technology might be dangerous for humans. In the final unit, *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*, students explore cosmology and the Big Bang, applying ideas about forces and energy from all five previous units on the largest scale.

This unit intentionally incorporates, in the moment, a number of activities that would typically take place in a "Unit 0." These include co-construction of Community Agreements, use of a Progress Tracker, and development of energy transfer diagram conventions. We recommend that you begin this unit at the start of the school year, following any requirements in your school or district.

What is the anchoring phenomenon, and why was it chosen?

This unit is anchored by the story of the 2021 power crisis in Texas and the accompanying design problem of improving the reliability of our own electric infrastructure. This event provides a rich context in which to investigate the nature of electrical energy transfer, the stability and change of energy inputs and outputs, the impact of energy transfer on our everyday lives, and the social/environmental trade-offs inherent in sourcing energy from Earth's systems. Over the course of the unit, students read about what happened in Texas and analyze multiple types of real data from the event. They investigate each part of the electrical system at various scales, from designing investigations using a simulation of the inside of a wire, to building their own working generators. They also model an electric grid in the classroom using power strips, alligator clips, LED bulbs, and cardboard buildings.

The Texas blackouts anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations, based on the results of a survey administered to almost 1,000 students across the country and in consultation with external advisory panels that included teachers, subject matter experts, and state science administrators. This phenomenon includes a strong engineering component linked to a complex global problem, and includes humans and human activity in the systems under study. The full physics course is designed to purposefully highlight various types of phenomena. Although we design to privilege the interests of students to whom we owe an educational debt, we must not essentialize minoritized groups by assuming that a trend in the data equates to homogenous interests and experiences. Providing a diverse suite of entry points into content and practices creates more opportunities for every student to connect with the content.

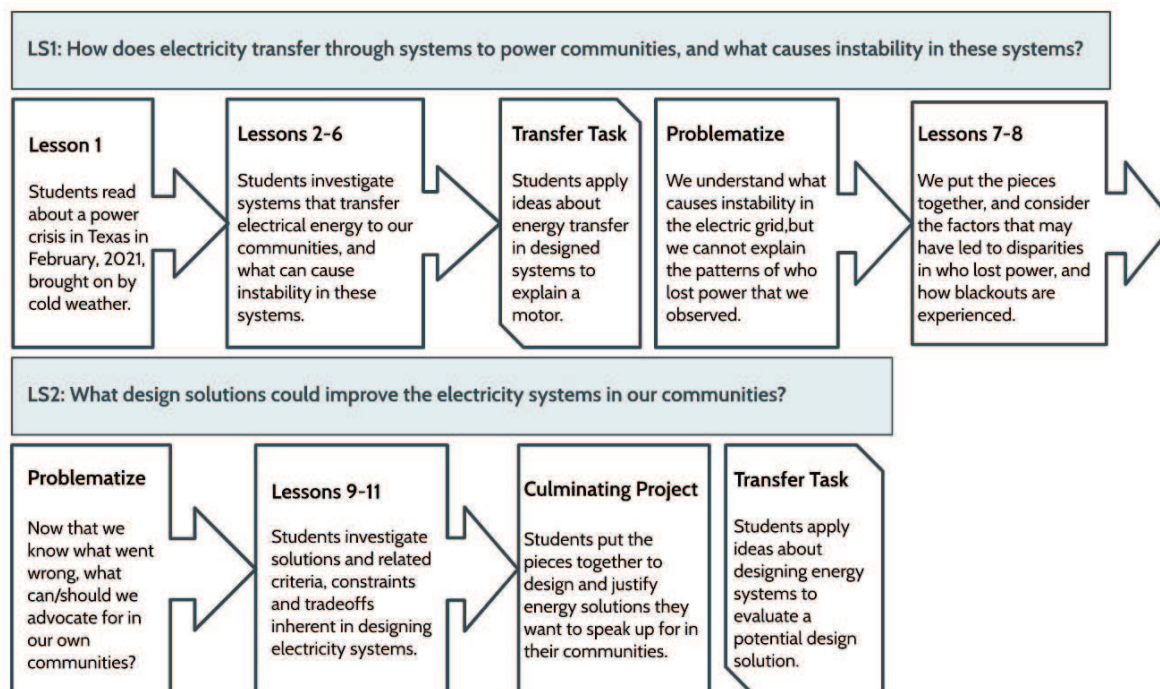
The blackouts phenomenon was chosen for the following reasons:

- Students showed high interest in explaining electricity-related phenomena.
- To provide a diverse suite of entry points across the course, we sought an event that allowed students to consider a relevant societal problem.
- Teachers and administrators saw the phenomenon as interesting and on grade band.
- Explaining the mechanisms that bring electricity to communities grounds abstract ideas about energy transfer in a real-world context.
- Explaining the phenomenon addresses all the DCIs in the bundle at a high school level.
- Explaining the phenomenon requires the use of mathematical thinking at a middle school level, helping students transition into high school physics.

How is the unit structured?

The unit is organized into two lesson sets. In the **first lesson set (Lessons 1-8)**, students read articles about an energy crisis in Texas that left much of the state in the dark. They develop models for how energy transfers through systems when the electricity grid is stable and when conditions change. They document the energy infrastructure in their school, homes, and community, and look for patterns that can provide clues as to how energy transfers. They follow these clues to an electrical outlet, dissect a power strip to investigate circuits, then wire several power strips together inside cardboard boxes to simulate the wiring of a small model community complete with substations and a battery “power plant.” They investigate various sources of power and determine that supply (energy input) and demand (energy output) must be equal to keep the system stable. They begin to keep track of engineering solutions and constraints, and trace the energy back to a generator in the power plant, build generators, and model energy flow through electric and magnetic fields to explain how those work. They “zoom in” on the wires to understand the particle nature of electrical energy transfer, and then “zoom back out” to put the pieces together and explain how an imbalance of inputs and outputs caused the energy crisis they read about. In Lessons 7-8, they problematize the explanation for what happened in Texas, motivating them to investigate the cause of disparities in the pattern of power outages on state, county, and municipal scales, using data and computational models, and talk about how outages have an inequitable impact on people in low-income neighborhoods due to existing disparities.

In the **second lesson set (Lessons 9-11)**, students turn their attention to their own community and consider what decisions they need to make to design more reliable power systems that meet their specific needs. They investigate considerations and trade-offs associated with using battery storage to improve reliability of renewable and low-carbon energy sources, including chemical, mechanical, and thermal solutions. Finally, they put the pieces together to design energy solutions they want to advocate for in their communities. Students apply these ideas in a culminating project that begins in Lesson 10, and a transfer task in Lesson 11.



What elements of the NGSS three dimensions are developed in this unit?

As noted above, this unit is designed to introduce students to the concept of **energy transfer** in a relevant and grounded context. **Asking questions and defining problems** is **intentionally developed** across this unit, beginning in Lesson 1 when students start to define the design problem that will drive the second half of the unit: how to **address global challenges** such as severe weather events, a growing population, climate change, and accelerating land use by making and advocating for **informed energy design decisions** that align to community values. In the first lesson set, students look closely at an energy crisis in Texas in 2021 to understand and model the conditions under which energy systems are stable, and when those change. **Stability and change** is **intentionally developed** as students return to the idea of reliability throughout the unit, using it to drive their design thinking. In the second lesson set, as students apply their ideas about energy transfer through electrical systems to design a plan for their own community, **constructing explanations and designing solutions** is **intentionally developed** in the context of engineering.

Analyzing and interpreting data is **intentionally developed** over the entire unit, as students look at and analyze various types of data to understand **energy systems**, and **evaluate design solutions**, including graphs of energy supply and demand from Texas, data generated by a simulation of electrons in a wire, interview responses collected from friends and family, and data generated by a computational model to describe their design solutions (the *Energy Grid Calculator*).

Developing and using models is **intentionally developed** in this unit, as students model **energy inputs, outputs, and transfer** through systems at various scales to understand how our energy grid works. Students model the **transfer of energy through electric and magnetic fields** in a generator, the transfer of energy through wires, **including energy loss to the surroundings**, and the transfer of energy into storage solutions like batteries. To support using these energy models to make sense of the electrical systems, **energy and matter** and **systems and system models** are both **intentionally developed** throughout the unit.

Although not intentionally developed, **planning and carrying out investigations** is **key to the sensemaking** in this unit, as students use a simulation to produce data to answer questions about electricity in wires. Also **key to the sensemaking** is **mathematics and computational thinking**, as students use middle school mathematics to understand phenomena such as energy loss, and to inform evaluation of the scalability of various design solutions. Also **key to the sensemaking** is **obtaining, evaluating, and communicating information**, which students engage in throughout the unit. **Scale, proportion and quantity, cause and effect, structure and function**, and **patterns** are also **key to the sensemaking** in several lessons.

This unit builds toward these performance expectations:

HS-PS2-5* Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1† Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
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 positions 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.
HS-ESS3-2† Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
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 impacts.
HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

*This performance expectation is developed across multiple units. This unit reinforces these NGSS PEs in a physics context.

†This performance expectation is developed across multiple courses. This unit reinforces or works toward these NGSS PEs that students will have previously developed in the OpenSciEd chemistry and/or biology courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
This unit intentionally develops students' engagement in these practice elements: 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. The following elements of this practice are intentionally developed across this unit: • Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables. • Ask questions to clarify and refine a model, an explanation, or an engineering problem. • Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. • Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. Developing and using models in 9–12 builds on K–8 experiences 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. The following elements of this practice are intentionally developed across this unit: • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.	PS2.B: Types of Interactions • Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4) • Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space: Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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. • "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. (secondary) • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. PS3.B: Conservation of Energy and Energy Transfer • Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. • Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged	This unit intentionally develops students' engagement in these crosscutting concept elements: Systems and System Models. A <i>system</i> is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems. The following elements of this crosscutting concept are intentionally developed across this unit: • Systems can be designed to do specific tasks. • Models (e.g., physical, mathematical, and computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. Energy and Matter. Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior. The following elements of this crosscutting concept are intentionally developed across this unit: • The total amount of energy and matter in closed systems is conserved. • 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. • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.

particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

- The availability of energy limits what can occur in any system.

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.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
Analyzing and interpreting data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. The following elements of this practice are intentionally developed across this unit: • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. 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. 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. The following element of this practice is intentionally developed across this unit: • 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. Elements from the following practices are also key to the sensemaking in this unit: • Using Mathematics and Computational Thinking. • Planning and Carrying Out Investigations • Obtaining, Evaluating, and Communicating Information	ESS3.A Natural Resources • All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2) ETS1.A: Defining and Delimiting Engineering Problems • 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 may also have manifestations in local communities. (HS-ETS1-1) ETS1.B: Developing Possible Solutions • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical, and in making a persuasive presentation to a client about how a given design will meet their needs. (HS-ETS1-4)	Stability and Change. For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand. • Much of science deals with constructing explanations of how things change and how they remain stable. Systems can be designed for greater or lesser stability. Elements from the following crosscutting concepts are also key to the sensemaking in this unit: • Patterns • Structure and Function • Cause and Effect

*“Disciplinary Core Ideas” are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. DOI: <https://doi.org/10.17226/13165>. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

Connections to the Nature of Science (NOS) and Engineering, Technology, and Applications of Science (ETS)

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Science Addresses Questions About the Natural and Material World. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.	These ideas are woven throughout the unit, but appear at the forefront of Lessons 7 and 8, when students learn about disparities in who lost power in Texas. Students reflect on how human decision-making interacted with natural systems to cause these disparities, and consider whether decisions made by the power company were fair.
Science Addresses Questions About the Natural and Material World. Science knowledge indicates what can happen in natural systems--not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.	In Lesson 10, students figure out that the way we extract energy sources from Earth's systems can have a profound impact on those systems. They read about how, if we want to prevent further damage, we need to make decisions that reflect what we value. They go on to interview their friends and families to learn about what criteria they value most, and reflect on how values impact engineering decision-making.
Science Addresses Questions About the Natural and Material World. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.	In Lesson 8, students listen to a podcast in which a researcher explains that even if harmful decisions were unintentional, that doesn't mean we shouldn't strive to do better.
Science Is a Human Endeavor. Science and engineering are influenced by society, and society is influenced by science and engineering.	In Lesson 2, students learn about the human-made structures we see every day in and around our homes and school, and how science ideas shape these structures, which have in turn changed the way we live.

Connections to Engineering, Technology, and Applications of Science (ETS)	
Which elements of ETS are developed in the unit?	How are they developed?
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.	In Lesson 2, students create a poster to remind themselves of our responsibility for considering our own safety and the safety of others whenever we are doing investigations. In Lessons 3 and 10, students learn about how extracting energy sources from Earth's systems can have a profound impact on those systems. In Lesson 8, students listen to a podcast in which a researcher explains that even if harmful decisions were unintentional, that doesn't mean we shouldn't strive to do better.
Influence of Science, Engineering, and Technology on Society and the Natural World. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1) (HS-ETS1-3)	In Lesson 10, students identify costs and benefits associated with various energy sources in a jigsaw, and use these to articulate trade-offs. At the end of the lesson, in an Electronic Exit Ticket aligned to this engineering connection, students reflect explicitly on why costs and benefits are so important.

How does the unit build three-dimensional progressions across the course and the program?

OpenSciEd units support students in integrated development and use of the three dimensions. No one dimension can be developed in isolation from the others, as reflected in three-dimensional Lesson-Level Performance Expectations (LLPEs) which detail the specific dimensions and elements used and assessed in each lesson. However, some practices and crosscutting concepts are more productive for investigating particular anchoring phenomena, so focal practices and crosscutting concepts are articulated in each unit. All 46 SEP and 29 CCC elements are developed at some point in the high school OpenSciEd program, so all elements of a given SEP or CCC may not be present even in a unit that emphasizes developing that SEP or CCC.

This unit uses and builds upon the following **Disciplinary Core Ideas (DCIs)** and other science ideas that students should have previously developed in the **OpenSciEd High School Biology and Chemistry courses**:

- We can trace energy flow in systems using computational models because energy is conserved. (*OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*)
- Electrons move toward different charges and away from like charges, transferring electrical energy, and move particularly easily through metals. (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*)
- Energy flows through Earth's systems, including the atmosphere, hydrosphere, geosphere, and biosphere. (*OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*)
- Energy can be transferred into and out of, and be stored in, magnetic and electric fields. (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*)

This unit also reinforces and builds from the following **DCI elements** from the **OpenSciEd Middle School sequence**:

- Energy flows through Earth's systems. (*OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*)
- Magnets have invisible fields through which objects can interact and energy can transfer without contact. (*OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*)

This unit uses and builds upon high school level **Science and Engineering Practices (SEPs)** and **Crosscutting Concepts (CCCs)** that students should have previously developed in **OpenSciEd High School Biology and Chemistry**, and will continue to build in future units. The progressions of these practices and concepts across the program are as follows:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
Biology	Cancer Unit	Serengeti Unit, Fires Unit	Fires Unit, Natural Selection Unit	Natural Selection Unit, Cancer Unit	Serengeti Unit	Fires Unit, Cancer Unit, Natural Selection Unit	Speciation Unit	Cancer Unit, Speciation Unit
Chemistry	Polar Ice Unit, Oysters Unit	Electrostatics Unit, Space Survival Unit	Polar Ice Unit	Fuels Unit	Polar Ice Unit, Oysters Unit	Fuels Unit	Fuels Unit	Electrostatics Unit, Space Survival Unit
Physics	Electricity Unit, Cosmology Unit	Electricity Unit, Microwave Unit	Microwave Unit	Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit	Vehicle Collisions Unit, Meteors Unit	Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit	Vehicle Collisions Unit	Cosmology Unit, Microwave Unit

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	Natural Selection Unit, Speciation Unit	Cancer Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit	Serengeti Unit	Fires Unit, Cancer Unit, Serengeti Unit	Fires Unit, Serengeti Unit	Cancer Unit	Speciation Unit, Serengeti Unit
Chemistry	Electrostatics Unit, Space Survival Unit	Oysters Unit, Fuels Unit	Electrostatics Unit, Oysters Unit	Polar Ice Unit	Polar Ice Unit, Fuels Unit	Space Survival Unit	Oysters Unit
Physics	Cosmology Unit, Vehicle Collisions Unit, Earth's Interior Unit	Vehicle Collisions Unit, Earth's Interior Unit	Meteors Unit, Earth's Interior Unit	Electricity Unit, Vehicle Collisions Unit, Microwave Unit	Electricity Unit, Earth's Interior Unit	Earth's Interior Unit, Vehicle Collisions Unit	Electricity Unit, Cosmology Unit

What are some common ideas that students might have?

Students will come into the unit with many ideas about energy derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with movement, and conversations with parents, friends, and family members. Some of these relevant ideas are:

1. Energy has distinct forms that are fundamentally different from each other (i.e., electrical, thermal, kinetic, chemical, and sound energy).
2. Energy is only a property of living things (i.e., a rock has no energy).
3. Energy is a force--these two words are interchangeable (note that students will explicitly unpack the distinction between energy and forces in Unit 2).
4. Energy is only associated with motion, so a rock being held at height “has no energy.”
5. Energy of motion (kinetic energy) is only associated with macroscopic motion (i.e., pressing hard on a wall does not transfer energy because we do not see the wall move; in fact, the matter is compressed on a particle scale).
6. Energy causes things to happen (in fact, it is a force that is causal).
7. Energy is fuel (we often use *energy* as a shorthand to describe a fuel like coal or petroleum--this is an everyday use for the term).
8. Energy is something we can will to move around our bodies or the world.
9. Energy is a thing, or “stuff.”
10. Energy is light waves.

In fact, energy is not stuff; it is a quantitative property of stuff, often described as “the ability to do work.” But “doing work” doesn’t mean much in everyday language beyond homework, yardwork, and jobs, and can in fact be more confusing to students. In physics, *work* is when something moves because it has been pushed or pulled. *Energy* is the ability of something to make something move through a push or a pull, with or without contact. And when the work is done to impart that motion through a push or a pull, energy is *transferred*.

It is valuable to think of such ideas not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. For example, in this unit, students begin to use the term *electrical energy* as a distinct energy “form” (see relevant idea 1 above). They figure out over the course of the lesson that electrical energy on a particle scale looks very familiar: electrons (stuff) pushing on each other and making each other move, thus transferring energy along a wire. They know from chemistry that *thermal energy transfer* is simply atoms and molecules pushing each other. *Potential energy*, such as that stored in a rock that has been lifted off the ground, is the ability of that rock to move if someone lets go, pulled this time by a gravitational field. *Fields* are simply a way to apply these energy-transferring pushes without physical contact. So even though energy forms are not real in a scientific sense, building explicitly from these ideas about distinct forms to draw connections is a productive pedagogical tool that helps students construct a new, more accurate conceptual model for energy transfer.

How will I need to modify the unit if taught out of sequence?

This is the first unit of the High School Physics Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications need to be made if physics is taught first, or if this unit is taught later in the Physics course. These include the following adjustments:

- If this unit is taught before OpenSciEd High School Chemistry, supplemental teaching of the particle model of matter will be required, including conceptual understanding of the nature of electrons, nuclei, and atoms.
- If it is taught later in the school year, additional supplementary materials related to forces should be incorporated into class discussions to help students integrate a “forces and energy” perspective.
- If it is taught as part of an AP Physics course, be prepared to provide students with additional support around equations that are not treated in depth. Extension opportunities to support students who want to go on to AP Physics are provided.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

The following are example options to shorten or condense parts of the unit without eliminating important sensemaking:

- Lessons 2, 5, 6, and 7: You can film demonstrations in Electric City ahead of time and cut these investigations from the unit. This reduces the number of hands-on activities available to students, but cuts time significantly.
- Lessons 9-11: The second lesson set addresses engineering performance expectations. If these are not a priority for your school or district, you can end the unit after putting the pieces together in Lesson 8. Students will not have the opportunity to design their community solutions.

To extend or enhance the unit, consider the following:

- Lesson 2: Give students the opportunity to design and build Electric City, rather than having the buildings and structures pre-assembled. Students can model the city after their own community, and spend time experimenting with various configurations to see how that affects the reliability of the system.
- Lesson 6: This lesson includes guidance on how to provide a coherent enrichment experience for students who are interested in learning more about circuits, or who have met and exceeded the performance expectations. These might also be helpful if your state has standards related to electricity and circuits in addition to those laid out in the NGSS. Look in the *Teacher Guide* for the heading “Extension opportunity” to find optional enrichment support.
- Lesson 11: Give students additional time and resources to complete the culminating task. Consider planning an assembly, or inviting friends, family, and community members into the classroom to see the presentations.
- All lessons: Remove scaffolds provided with Science and Engineering Practices (SEPs) as a way to give students more independent work with the elements of these practices.

What mathematics concepts will students engage with in the unit?

During the **first lesson set**, students are introduced to a tool, the Energy Transfer Model, for representing how energy flows in a system and the types of matter interactions associated with it. This model uses a simple quantitative approach to make sense of energy transfer and to determine whether the amount of energy increases or decreases as the energy flows. Quantifying energy supports students in thinking about conservation of energy while helping them draw connections between the system's stability and reliability. Students use a data visualization and analysis tool (CODAP) to identify the correlation coefficient of a linear fit between various demographic variables and the percentage of people who lost power in a given Texas county in February 2021. They explore issues with the scale of the data used to explain the lack of correlation, and reasons why causal relationships cannot be determined from a correlation in this context. In *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*, students will use their ideas about correlation between two variables to investigate linear and nonlinear relationships.

In the **second lesson set**, students continue using quantitative reasoning to consider how to model the role of a battery in the flow of energy in a system. This supports students in making connections between energy storage and reliability. Students also apply ratios and unit conversions to calculate the costs and land use area of various energy storage systems.

This unit does not assume fluency with the mathematical practices listed below; rather, students develop these practices as part of the sensemaking. Thus, these standards are not so much prerequisites as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards listed below:

Category	Code	Domain and Heading	Standard	Relevant Lessons
Number and Quantity	CCSS.MATH.CONTENT.HS.N-Q.2	Quantities: Reason quantitatively and use units to solve problems.	Define appropriate quantities for the purpose of descriptive modeling.	3, 9
Functions	CCSS.MATH.CONTENT.HS.N-Q.1	Interpreting Functions: Interpret functions that arise in applications in terms of the context.	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.	9, 11
Statistics and Probability	CCSS.MATH.CONTENT.HS.S-ID.8	Interpreting Categorical and Quantitative data: Interpret linear models.	Compute (using technology) and interpret the correlation coefficient of a linear fit.	7

	CCSS.MATH.CONTENT.HS.S-ID.9	Interpreting Categorical and Quantitative data: Interpret linear models.	Distinguish between correlation and causation.	8
--	-----------------------------	---	--	---

See individual lessons referenced above for details.

What strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies that are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. These equity goals are supported through several specific strategies, such as: (1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for students to engage in learning experiences; (2) developing and supporting classroom agreements that encourage a safe learning culture; (3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and (4) offering specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the *Teacher Guides* in sidebar callout boxes with these headings:

- Attending to Equity
- Supporting Emerging Multilingual Learners
- Supporting Universal Design for Learning
- Additional Guidance
- Alternate Activity
- Key Ideas
- Discussion

What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model casts the teacher as a member of the classroom community, supporting students motivated by their own questions about phenomena to figure out scientific ideas. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach the lessons also builds incrementally. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) figured out in each lesson. Places to find this guidance include the “Where we are going” and “Where we are not going” sections of the lesson’s *Teacher Guide*. The expected student responses, keys, and rubrics also illustrate important science ideas that should be developed. The K-12 Science Framework is another great resource for learning more about the DCIs in this unit (ETS1.A: Defining and Delimiting Engineering Problems, ETS1.B: Developing Possible Solutions, PS2.B: Types of Interactions, PS3.A: Definitions of Energy, PS3.B: Conservation of Energy and Energy Transfer, PS3.C: Relationship Between Energy and Forces, ESS3.A Natural Resources), including what students have learned previously and where they are headed in high school.

In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of this unit’s phenomena and Performance Expectations bundle.

- To learn more about the crisis in Texas in February 2021:
 - **The Disconnect: Power, Politics and the Texas Blackout (podcast):** <https://www.npr.org/podcasts/1004840920/the-disconnect-power-politics-and-the-texas-blackout>
 - **The Timeline and Events of the February 2021 Texas Electric Grid Blackouts (report from the UT Austin Energy Institute):** <https://energy.utexas.edu/sites/default/files/UTAustin%20%282021%29%20EventsFebruary2021TexasBlackout%2020210714.pdf>
 - **Frozen Out in Texas: Blackouts and Inequity (Case Study from the Rockefeller Foundation):** <https://www.rockefellerfoundation.org/case-study/frozen-out-in-texas-blackouts-and-inequity/>
- To obtain statistics related to various energy sources and storage solutions:
 - **The United States Department of Energy:** <https://www.energy.gov/energy-sources>
 - **The U.S. Energy Information Administration:** <https://www.eia.gov/>
- To learn more about some of the difficult trade-offs associated with choosing energy sources and solutions:
 - **WA NI SKA TAN Alliance of Hydro-Impacted Communities:** <https://hydroimpacted.ca/>
 - **United Nations Climate Action:** <https://www.un.org/en/climatechange/science/causes-effects-climate-change>
 - **Wind Energy Technologies Office:** <https://www.energy.gov/eere/wind/advantages-and-challenges-wind-energy>

How do I support students' emotional needs?

The Texas power crisis of February 2021 anchoring this unit is a phenomenon that straddles the traditional divide between science and culture. Students read articles featuring interviews with real people who have experienced trauma. The Texas power outages resulted in hundreds of lives lost, and some students' lives and families may have been (or may still be) greatly affected. Before beginning this unit, **reach out to the counselor at your school** for student-specific support and strategies that might be needed in regard to the students in your class, and consider asking the counselor to join you on the first day of instruction. Also consider planning follow-up check-ins with the counselor in regard to any students who may need additional emotional support.

Often in science classrooms, we are focused on evidence and data. When addressing a phenomenon or design solution that straddles the nature-culture divide, like this one, supporting students in using a social and emotional lens rooted in empathy is also important. According to the CDC, "Adopting a trauma-informed approach is not accomplished through any single particular technique or checklist. It requires constant attention, caring awareness, [and] sensitivity." Make space for students to process information, and validate their feelings and reactions. Be aware that students who are struggling may demonstrate a variety of behaviors, including but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, change in body language or tonation. If you notice a student might be struggling, share what you are observing and ask whether they need some help.

Social awareness. In Lesson 1, giving students space to consider what these power outages were like can help support the development of their social awareness, one of the Collaborative for Academic, Social, and Emotional Learning (CASEL) five core competencies. *Social awareness* describes the abilities to understand the perspectives of and empathize with others, including those from diverse backgrounds, cultures, and contexts. Students have another opportunity in Lesson 11 to develop social awareness by thoughtfully taking the perspective of multiple stakeholders. It is important to help students imagine these roles, but also to support them in not essentializing the people in these groups. Point out that these categories are not monoliths, and that many of them interact with one another and with other social and professional identities.

Self-awareness. In Lesson 8, students learn about existing and inextricable economic, racial, and health disparities that impacted the way people experienced the power outages. Again, make space for them to process, and validate their feelings and reactions. Giving students a chance to think about how they feel in relation to the content of the podcast and the reading can help support the development of their self-awareness, another one of the CASEL five core competencies. *Self-awareness* describes the abilities to understand one's own emotions, thoughts, and values and how they influence behavior across contexts.

Responsible decision-making. In addition to developing self-awareness, students are given several opportunities to consider what choices they would make after considering their own emotions, which supports the development of another core competency that is highlighted over the second lesson set of this unit: responsible decision-making. *Responsible decision-making* describes the abilities to make caring and constructive choices about personal behavior and social interactions across diverse situations. This includes the capacity to consider ethical standards and safety concerns, and to evaluate the benefits and consequences of various actions for personal, social, and collective well-being.

Transformative SEL. The culminating task in Lesson 11 was designed to give students and educators an opportunity to engage in "transformative social and emotional learning." *Transformative SEL* describes a process "whereby young people and adults build strong, respectful, and lasting relationships that facilitate co-learning to critically examine root causes of inequity, and to develop collaborative solutions that lead to personal, community, and societal well-being." Rather than provide a fictional scenario, the task is designed to support students in taking agency, and to give them the tools to speak up in their local and global community for a better energy future that aligns with their values.

For more support around Social and Emotional Learning, visit <https://casel.org>.

For more trauma-informed strategies to support your students' emotional needs, visit <https://transformingeducation.org>.

What is the Learning in Places socio-ecological deliberation and decision-making framework?

This unit is informed by the Learning in Places socio-ecological deliberation and decision-making framework. This framework involves sensemaking across seven dimensions, which include making sense of both human and other-than-human values, needs, and behaviors across multiple temporal and spatial scales. The framework guides learners toward designing actions or making decisions for making change in adaptive and resilient ways.

Socio-ecological decisions are those made by individuals, communities, organizations, and institutions that are informed by and impact the natural world. These decisions are affected by relationships between humans and the natural world, called *nature-culture relations*. Nature-culture relations often vary by culture, context, and society, and affect which socio-ecological decisions are made and enacted. Understanding the connections between humans and the natural world is imperative for creating and sustaining socially and environmentally just decisions.

Some examples of this framework in action in this unit are:

- Students consider how disparities in access to resources makes the experience of decisions made by those in power very different in Lesson 8.
- Students are faced with decisions around designing and maintaining electrical infrastructure. In thinking about these decisions, they are asked to consider the needs of humans, and also of animals and the environment, when considering trade-offs in Lesson 10.
- Students consider the values that guide decision-making by considering the perspectives of interested parties in Lesson 10, interviewing their friends and families, and discussing the importance of values in energy decision-making.
- Students think about the geographies of their own region and how those will inform their design thinking in Lesson 11.

For more about socio-ecological deliberation and decision-making, visit <http://learninginplaces.org>.

Text and image courtesy of Learning in Places Collaborative (2021). Ethical Deliberation and Decision-Making in Socio-Ecological Systems Framework. Learning in Places website. <http://learninginplaces.org/frameworks/ethical-deliberation-and-decision-making-in-socio-ecological-systems-framework/>.



Learning in Places Collaborative (2021)

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students experience and discuss science ideas before they know the specific vocabulary words that name those ideas. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have co-developed that definition and can add the specific term to a Personal Glossary at the back of their science notebooks. These “definitions we co-develop” should be recorded using students’ own words whenever possible. On the other hand, “definitions we encounter” are “given” in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, definitions we encounter are helpful only in that lesson and need not be recorded in students’ glossaries. However, if a “word we encounter” will be frequently referred to throughout the unit, it should be added.

It is best for students if you create consensus definitions in the moment, using phrases and pictorial representations that the class develops together as they discuss their experiences in the lesson. When students co-create the meaning of a word, they “own” the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop student-friendly definitions that are also scientifically accurate.

The definitions we co-develop and encounter in this unit are listed in this document and in each lesson’s guide to help you prepare and to avoid introducing a word before students have earned it. They are *not* intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when allowed to experience them first as ideas they’re trying to figure out. Some lessons include built-in opportunities for students to add to their glossaries, but some do not. Offer this opportunity whenever students feel they have co-constructed a definition and it would be helpful to keep track of it, and encourage them to keep track of words from previous lessons that have become useful, in addition to new words.

Lesson	Words and Equations with Meanings We Co-Construct	Words and Equations with Meanings We Encounter
L1	electricity, energy, infrastructure, grid	electricity, energy, infrastructure, grid, reliable
L2	circuit, switch, ground, substation	incandescent, insulator, short circuit, broken circuit
L3		criteria, constraint, supply, demand
L4	reliability, efficiency, power	dispatchability
L5	generator, power plant, wind turbine, magnetic field	field
L6	electron, current	
L7	hypothesis, correlation, r^2	
L8		trade-off
L9	storage solution	pumped hydropower, flywheel
L10	costs, benefits	interested party, life-cycle analysis, dispatchability
L11		

HOME COMMUNICATION

Dear Parents, Guardians, and Caregivers,

Your child's physics class is starting a unit focused on the question *How can we design more reliable systems to meet our communities' energy needs?* as part of the OpenSciEd high school science curriculum. This unit is anchored by the story of a power crisis in Texas, and the accompanying design problem of improving the reliability of our own electric infrastructure. This event provides a rich context in which to investigate the nature of electrical energy transfer, the stability and change of energy inputs and outputs, the impact of energy transfer on our everyday lives, and the social/environmental trade-offs inherent in sourcing energy from Earth's systems.

Over the course of the unit, students will read about what happened in Texas and analyze multiple types of real data from the event. They will investigate each part of the electrical system at various scales, from designing investigations using a simulation of the inside of a wire, to building their own working generators. They will also model an electric grid in the classroom using power strips, alligator clips, LED bulbs, and cardboard buildings.

In the final lessons of the unit, students will consider engineering trade-offs, criteria, and constraints inherent in making decisions about our energy systems, and apply them in a final task: design a reliable energy solution that meets our communities' needs, as articulated by interviews with friends and family members. The task is designed to give students the tools to speak up in their local and global community for a better energy future—one that aligns with their own values and those of their families.

Losing power can be devastating, and recalling past experiences or learning about others' experiences can be triggering. If your child or someone close to your child has had experiences with sustained power outages that might be traumatic, please contact me at _____, if you are comfortable doing so. You can also contact the school counselor at _____. By knowing about these experiences in advance, we can be sensitive to students' needs and provide support if they experience any strong emotions during this unit.

Adolescents sometimes develop difficult behaviors after a traumatic experience. It is important for trusted adults to understand that these behaviors and emotions are common when children experience trauma. Students may be more aggressive or withdrawn, and go through periods of sadness, anger, or emotional "numbing." Contact a counselor if you see any of the following behaviors in your child:

- problems sleeping, nightmares
- changes in school performance
- truancy
- risk-taking behavior
- conflicts with peers
- new or increasing psychosomatic complaints, including stomachaches and headaches
- depression or suicidal thoughts

After a traumatic event, being able to talk to someone who is removed from the situation is often helpful to both adults and children. Children who have experienced trauma are best supported when their parents or trusted caregivers accept their feelings and are open to listen and talk. Let your child come to you. Do not overwhelm them if they are not ready to talk. Respect your child's need to take breaks.

If you have any questions about the content of this unit or would like to discuss anything further, I encourage you to reach out to me at _____.

Best,

Your name or signature here

Estimados padres, tutores y cuidadores:

La clase de física de su hijo está comenzando una unidad centrada en la pregunta *¿Cómo podemos diseñar sistemas más confiables para satisfacer las necesidades energéticas de nuestras comunidades?* como parte del plan de estudios de ciencias de la escuela secundaria de OpenSciEd. Esta unidad se basa en la historia de una crisis energética en Texas y el problema de diseño que la acompaña para mejorar la confiabilidad de nuestra propia infraestructura eléctrica. Este evento proporciona un rico contexto en el que investigar la naturaleza de la transferencia de energía eléctrica, la estabilidad y el cambio de las entradas y salidas de energía, el impacto de la transferencia de energía en nuestra vida cotidiana y las compensaciones sociales y ambientales inherentes al abastecimiento de energía de los sistemas de la Tierra.

A lo largo de la unidad, los estudiantes leerán sobre lo que sucedió en Texas y analizarán múltiples tipos de datos reales del evento. Investigarán cada parte del sistema eléctrico a varias escalas, desde diseñar investigaciones utilizando una simulación del interior de un cable hasta construir sus propios generadores funcionales. También modelarán una red eléctrica en el salón utilizando reglas, pinzas de cocodrilo, bombillas LED y edificios de cartón.

En las lecciones finales de la unidad, los estudiantes considerarán las compensaciones, los criterios y las limitaciones de ingeniería inherentes a la toma de decisiones sobre nuestros sistemas energéticos y los aplicarán en una tarea final: diseñar una solución energética confiable que satisfaga las necesidades de nuestras comunidades, como articulado mediante entrevistas con amigos y familiares. La tarea está diseñada para brindar a los estudiantes las herramientas para hablar en su comunidad local y global por un futuro energético mejor, uno que se alinee con sus propios valores y los de sus familias.

Perder energía puede ser devastador y recordar experiencias pasadas o conocer las experiencias de otros puede ser desencadenante. Si su hijo o alguien cercano a él ha tenido experiencias con cortes de energía sostenidos que podrían ser traumáticos, comuníquese conmigo al _____. Al conocer estas experiencias de artemano, podemos ser sensibles a las necesidades de los estudiantes y

brindarles apoyo si experimentan emociones fuertes durante esta unidad.

A veces los adolescentes desarrollan conductas difíciles después de una experiencia traumática. Es importante que los adultos de confianza comprendan que estos comportamientos y emociones son comunes cuando los niños experimentan un trauma. Los estudiantes pueden ser más agresivos o retraídos y pasar por períodos de tristeza, ira o "adormecimiento" emocional. Comuníquese con un consejero si observa alguno de los siguientes comportamientos en su hijo:

- problemas para dormir, pesadillas
- cambios en el rendimiento escolar
- ausentismo escolar
- comportamiento de riesgo
- conflictos con compañeros
- quejas psicósomáticas nuevas o crecientes, incluidos dolores de estómago y de cabeza.
- depresión o pensamientos suicidas

Después de un evento traumático, poder hablar con alguien que está alejado de la situación suele ser útil tanto para los adultos como para los niños. Los niños que han experimentado un trauma reciben mejor apoyo cuando sus padres o cuidadores de confianza aceptan sus sentimientos y están abiertos a escuchar y hablar. Deja que tu hijo venga a ti. No los abrumes si no están listos para hablar. Respete la necesidad de su hijo de tomar descansos.

Si tiene alguna pregunta sobre el contenido de esta unidad o desea discutir algo más, le invito a que se comuniquen conmigo al _____.

Sinceramente,

Su nombre o firma aquí

LESSON 1: What can we learn from a blackout in Texas about producing reliable energy for our communities?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

3 days



Hartmut Schmidt, Heidelberg

We explore a new phenomenon by reading a series of articles about widespread blackouts in Texas and by drawing on the experiences of our friends and family. We make an initial consensus model of what happens to our electricity production system when it is stable and during a blackout. We develop questions for our Driving Question Board and brainstorm initial ideas about ways we could design more reliable systems to meet our communities' energy needs. We decide to document the electricity infrastructure in our homes and communities to look for patterns that could help us understand how the system works and identify weaknesses.

NEXT LESSON

We will compare photos and drawings of structures that provide electricity. We will dissect a power strip and connect it to a battery to power multiple devices. We will develop a model of how structures of the power strip system enable it to transfer energy from one source to multiple devices. We test the effects of short circuits and broken circuits.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

1.A Develop a model of energy transfer through systems to explain how energy manifests as electricity in our communities, including how changes to an otherwise stable system could cause blackouts. (SEP: 2.3; CCC: 7.1; DCI: PS3.A.2, PS3.B.2, PS3.B.4)

1.B Ask questions to clarify and define the problem of how our community can generate energy by designing systems to address both local and global challenges. (SEP: 1.4; 1.8; CCC: 4.1; DCI: ETS1.A.2)

WHAT STUDENTS WILL FIGURE OUT

- The term *electricity* describes energy transfer that can power lights and other devices.
- There are several subsystems that we agree are important for understanding how energy transfers to power our communities when the system is stable and during a blackout.

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		SET THE STAGE FOR THE ANCHORING PHENOMENON Introduce the idea of phenomenon-based learning. Reveal the anchoring phenomenon for the unit: devastating widespread power outages in Texas in February 2021. Share initial reactions.	A-B	
2	25 min		JIGSAW: TEXAS BLACKOUTS ARTICLES Split the class into six groups and assign each group a short article to read and summarize together. Then reshuffle students into jigsaw groups to share across articles and have a discussion.	C-E	<i>Texas Article 1, Texas Article 2, Texas Article 3, Texas Article 4, Texas Article 5, Texas Article 6</i>
3	10 min		NOTICE OUTAGE PATTERNS Present a map of the Texas blackouts and have students capture noticings and wonderings in their notebooks. Make a public record of these ideas, and then turn and talk to share initial ideas about the cause of these patterns.	F-G	<i>Texas Outages Map</i> , chart paper or whiteboard
4	5 min		NAVIGATE: HOME LEARNING AND EXIT TICKET Orient students to where the class is going next with a home learning assignment and an exit ticket.	G-H	<i>Collecting Stories</i> , blank sheet of paper
End of day 1					
5	10 min		NAVIGATE: SHARE STORIES AND BROADEN TO RELATED PHENOMENA Begin broadening and initial modeling in small groups by sharing stories from the home learning and then discussing our community(s). Broaden to related phenomena as a class by brainstorming other causes of a blackout.	I-J	<i>Collecting Stories</i> , chart paper for Related Phenomena poster, markers
6	15 min		CREATE INITIAL MODELS AND CONDUCT A GALLERY WALK Have students use the handout to make individual models to explain blackouts and energy transfer in the system. Set up a gallery walk for students to compare their initial models to support the process of building consensus during the next class.	K-L	<i>Initial Models</i>
7	5 min		DISCUSS COMMUNITY AGREEMENTS IN A SCIENTISTS CIRCLE Form a Scientists Circle for the first time and establish shared agreements for communication and collaboration.	M-N	<i>Community Agreements</i> , Community Agreements poster
8	15 min		COME TO CONSENSUS IN A SCIENTISTS CIRCLE Hold a Consensus Discussion to come to agreement around how to model the systems and interactions that bring power to our communities through the lens of energy transfers. Introduce <i>Progress Tracker</i> .	O-Q	<i>Progress Tracker</i> , chart paper for Initial Consensus Energy Transfer Model poster, markers, sticky notes (3x3)
End of day 2					
9	10 min		NAVIGATE: TEST OUR MODEL IN TEXAS Have students turn and talk and then bring the class together to apply our initial consensus model to explain the pattern of power outages we noticed in Texas in February 2021.	R	Initial Consensus Energy Transfer Model poster, chart paper for Ideas for Data/Investigations We Need poster, markers

Part	Duration		Summary	Slide	Materials
10	20 min		BUILD THE DQB Have students write initial questions and gather in a Scientists Circle. Build the DQB as a class.	S-T	sticky notes (3x3), black markers, <i>Texas Outages Map</i> , DQB Student Reference handout (optional), Related Phenomena poster, Initial Consensus Energy Transfer Model poster, DQB
11	10 min		BRAINSTORM DESIGNS AND FURTHER INVESTIGATION Introduce the engineering design challenge and brainstorm additional data and investigations.	U	Ideas and Investigations We Need poster, markers
12	5 min		NAVIGATE: REFLECT AND ASSIGN HOME LEARNING Reflect on the anchor experience. Assign home learning by asking students to take photos or make sketches of the electricity infrastructure around them. You will return to this at the start of the next lesson. Set up students' Personal Glossaries.	V-W	

End of day 3

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Texas Outages Map</i> <i>Collecting Stories</i> - blank sheet of paper <i>Initial Models</i> <i>Community Agreements</i> <i>Progress Tracker</i> - sticky notes (3x3) - black markers - DQB Student Reference handout (optional)	<i>Texas Article 1</i> <i>Texas Article 2</i> <i>Texas Article 3</i> <i>Texas Article 4</i> <i>Texas Article 5</i> <i>Texas Article 6</i>	- chart paper or whiteboard - chart paper for Related Phenomena poster - markers - Community Agreements poster - chart paper for Initial Consensus Energy Transfer Model poster - sticky notes (3x3) - Initial Consensus Energy Transfer Model poster - chart paper for Ideas for Data/Investigations We Need poster - Related Phenomena poster - DQB - Ideas and Investigations We Need poster

Materials preparation (25 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Review the unit front matter for an overview of how disciplinary core ideas, crosscutting concepts, and science and engineering practices are developed in this unit.

Review the unit front matter for an overview of how this unit is designed to (1) help students develop and apply social and emotional skills and (2) consider how to apply science ideas to address inequities they see in the world.

Prepare chart paper for posters. The posters you will make in this lesson are as follows:

- Related Phenomena
- Initial Consensus Energy Transfer Model
- Ideas for Data/Investigations We Need
- DQB
- Community Agreements

For the Community Agreements poster, prepare the chart paper by making 4 equal rows. On the left, label each row with the categories listed in *Community Agreements*, leaving plenty of room on the right to add agreements.

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

This lesson presents a specific example of widespread power outages on day 1 and then gives students a chance to bring in their own examples on day 2. The articles about Texas are meant to (1) provide a concrete shared example for the class to consider and model; (2) elicit student experiences with blackouts and their ideas about energy production; (3) introduce a controversy that requires more data to unravel: whether over-reliance on windmills could have caused the Texas disaster; and (4) prompt students to consider the complexity of designing a system that will meet all the needs of every community.

Because this is the first lesson in a new unit, the goal is not to establish any ideas associated with the relevant DCI (ESS2.B), but rather to elicit student ideas related to that DCI. The DCI elements that students will be thinking about in this lesson include:

- **PS3.A.2** At the macroscopic scale, energy manifests itself in multiple ways, ~~such as in motion, sound, light, and thermal energy.~~ (HSPS3-2) (HS-PS3-3)
- **PS3.B.4** The availability of energy limits what can occur in any system. (HS-PS3-1)
- **PS3.B.2** Energy ~~cannot be created or destroyed, but it~~ can be transported from one place to another and transferred between systems. (HS-PS3-1) (HS-PS3-4)
- **ETS1.A.2** 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. (HS-ETS1-1)

Students should already have worked with the idea of energy in the context of chemistry and/or biology and should understand that electricity is one macroscopic manifestation of energy. In the next two lessons, we will quickly uncover that our electricity infrastructure is a series of parallel circuits, and that oscillating electrons in the wire provide the means for energy transfer.

Students will encounter the following words in this lesson: *electricity, energy, infrastructure, grid*. Students will also encounter and briefly discuss the word *reliable*, but will not develop a meaning for reliable until Lesson 3. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

This unit is not about circuits. Lesson 2 delves briefly into circuits concepts as a bridge to energy. Throughout the unit, students will review and apply middle school ideas about electricity and circuits, but only to provide a context for high school level ideas about energy conservation and transfer. This culminates in a complex design challenge with both local and global implications for our "energy grid," not a culminating project about circuits. This unit is also not about forces. Students may use that vocabulary, but we recommend using the vocabulary of "pushes" and "pulls" right now, to allow students to develop a solid conceptual framework for energy before thinking about forces. Forces will be explicitly introduced in the second unit, with a focus on the interplay of energy and forces.

LEARNING PLAN for LESSON 1

1 · SET THE STAGE FOR THE ANCHORING PHENOMENON

5 min

MATERIALS: None

Introduce the idea of phenomenon-based learning. Say, *Our work in class this year is going to center on our questions about phenomena-- events or things we can observe but not yet completely explain. Each unit will be anchored by a phenomenon, and the questions you all have about it will drive our work in this class for weeks to come as we try to figure them out. This may be different from other classes where someone taught you new ideas right away. But in this class, we are going to spend a few periods exploring a phenomenon, developing initial explanations about it, and considering other experiences we have had that could be related to it. This will help us pull in different ideas and perspectives and develop questions that reflect what we are all curious about.*

Introduce what happened in Texas. Present slide A and read the slide aloud: *In February 2021, over 11.8 million Texans lost access to electricity to heat and light their homes, refrigerate their food, and charge their devices. For many people, the power outages lasted for several days. Hundreds of people died as a result.*

Give students a chance to share initial reactions. Move to slide B. Ask students if they heard about this, or knew anybody who was impacted. Give students 1-2 minutes to share their ideas with the person next to them. Acknowledge that this story can be upsetting, and that people lost their lives as a result of these power outages. *

ADDITIONAL GUIDANCE

The purpose of this brief discussion is to (1) give students a chance to share what they may have heard about the Texas power outages and (2) provide space to share their initial reactions to a complex and potentially upsetting story. Remember that this anchoring lesson is about surfacing ideas and experiences related to the phenomenon, not about explaining or having the right answer. If no physics ideas emerge at this point, do not bring them up. They will emerge organically through students' investigations to answer their questions about the phenomenon.

* ATTENDING TO EQUITY

Often in science classrooms, we focus on evidence and data. When addressing a phenomenon or design solution that straddles the nature-cultural divide, like this one, supporting students in using an empathy or social and emotional lens is also important. The Texas power outages resulted in hundreds of lives lost, and for some students, their lives and families may have been (or may still be) greatly affected. For more support around teaching at the nature-cultural divide, and specifically around framing decision making related to these kinds of phenomena, visit <http://learninginplACES.org/frameworks/ethical-deliberation-and-decision-making-in-socio-ecological-systems-framework/>.

2 · JIGSAW: TEXAS BLACKOUTS ARTICLES

25 min

MATERIALS: science notebook, *Texas Article 1*, *Texas Article 2*, *Texas Article 3*, *Texas Article 4*, *Texas Article 5*, *Texas Article 6*

Assign students to read articles. Present **slide C**. Assign each student to one of six groups and distribute the corresponding Texas Article (six readings listed below) to each student. * Ask them to read their assigned articles individually and then respond to the slide's Stop and Jot prompt on a blank piece of paper that they can insert into their science notebook. * These articles are short, so give students about 10 minutes for this task.

1. *Texas Article 1*
2. *Texas Article 2*
3. *Texas Article 3*
4. *Texas Article 4*
5. *Texas Article 5*
6. *Texas Article 6*

SCIENCE NOTEBOOK



Keeping a science notebook allows students a space in which to reflect and communicate their developing understandings about science ideas and to track changes in those understandings. Each student should have a binder that will serve as their science notebook for the course. Students can use large dividers to indicate the start of a new unit. They can use smaller dividers or sticky notes to create three sections within the unit: (1) the main science notebook, (2) the Progress Tracker, and (3) the Engineering Design Tracker.

Arrange students in six article groups. Ask all the students who read article 1 to sit together at table 1, all the students who read article 2 to sit together at table 2, and so on. In a class of 30, for example, you would have 6 article groups of 5 students each. Present **slide D**, and ask students to work together in their groups to summarize their article. Remind them to make sure each person takes notes so they are ready to share with the jigsaw group they will work with next. Give students about 5 minutes for this discussion. *

ALTERNATE ACTIVITY

For students who need additional support with reading comprehension, the skill of *summarizing* can be difficult because they have to separate details from main ideas and parse information into the most essential points. These students may benefit from developing a summary based on the following prompts: *What happened with the weather during the storm? What happened to the electricity? How were people impacted?*

Reshuffle students into jigsaw groups. Ask students to count off within their article groups and then reshuffle into jigsaw groups, with the 1's relocating to table 1, the 2's relocating to table 2, and so on. In a class of 30, you would now have 5 jigsaw groups of 6 students each. Present **slide E** and tell students that they will each have 2 minutes to share the summary of their article. Set a timer at the front of the classroom for 2 minutes five times to make sure students stay on track.

Then ask students to spend 5 minutes discussing the following prompts from **slide E** in their groups:

1. How did a winter storm in Texas become fatal?
2. What do you think it was like to experience a power outage like this? *
3. Are there any articles that contradict one another? How?
4. Why do you think electricity is described as an "essential" utility? What are the dangers for a community that loses electricity?

* ATTENDING TO EQUITY

The Texas Articles are written at different reading levels and vary in length. *Texas Article 2* and *Texas Article 6* are most accessible, while *Texas Article 3* and *Texas Article 4* are most challenging. At your discretion, either count students into random groups 1-6, or assign them into intentional, mixed-ability reading groups, with the students who need more reading support in groups 2 and 6 along with students who do not need the extra support.

* ATTENDING TO EQUITY

Supporting emergent multilinguals: Students should be encouraged to record their ideas using linguistic (e.g., written words) and nonlinguistic modes (e.g., photographs, drawings, tables, graphs, mathematical equations, measurements). This is especially important for emergent multilingual students because making connections between written words and nonlinguistic representations helps students generate richer explanations of scientific phenomena.

* ATTENDING TO EQUITY

Social and emotional learning: Giving students a chance to consider what these power outages were like can help support the development of students' *social awareness*, one of the Collaborative for Academic, Social, and Emotional Learning (CASEL) five core competencies. Social awareness describes the abilities to understand the perspectives of and empathize with others, including those from diverse backgrounds, cultures, and contexts. For more support around social and emotional learning, visit <https://casel.org/>.

3 · NOTICE OUTAGE PATTERNS

10 min

MATERIALS: science notebook, *Texas Outages Map*, chart paper or whiteboard

Present a map of the Texas blackouts. Distribute *Texas Outages Map*, which has a map of the Texas blackouts in 2021. Present **slide F**. *

Record noticings and wonderings. Give students about 2 minutes to capture noticings and wonderings about the map on a T-chart in their notebooks as shown on the slide. Then elicit these student ideas and spend 4 minutes making a public record of them at the front of the room on a T-chart.

Expected Noticings:

- It didn't happen everywhere in Texas, and some counties got it worse than others, particularly in the south.
- It got worse over time, and then got better.

Expected Wonderings:

- Why didn't it happen in northwest Texas? Did it happen more where the weather was worse?
- Why were some people affected more than others? Does this map on to economic status or population density?
- Did it depend on the electricity sources? Where does Texas get its electricity, and does this vary?
- What is happening in the "islands" where people didn't lose power? Why didn't everyone lose power at once?

Present **slide G** and have students turn and talk briefly to share initial ideas about the cause of these patterns.

* SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

Ask students what the map represents and how to read it, making sure that everyone understands that the color gradient represents the percent of customers without power in that county. You can point to a county and check the class's understanding by asking, *How were the people in this county affected by the power outages? How can you tell?*

4 · NAVIGATE: HOME LEARNING AND EXIT TICKET

5 min

MATERIALS: *Collecting Stories*, blank sheet of paper

Motivate the home learning. Continue to display **slide G**. Say, *Texas is not the only place where blackouts occur, causing people to lose access to heat and other essentials. How many of you have experienced a blackout or something similar?* Wait for a show of hands. Then ask, *What could we do to gather even more stories about related phenomena?* Look for students to suggest asking friends and family.

Say, *I bet there is a lot we can learn from your stories, and the stories of those in your families and communities. Let's gather some of these stories for next time.*



Assign the home learning. Distribute *Collecting Stories*, present **slide H**, and explain the assignment at the top of the slide. In addition to recording their own experiences, students should ask at least one person from their family or community, or a friend who is not in the class, if they have ever experienced a blackout; and if so, they should ask them the questions on the handout. Tell students, *Keep track of your interviewees' ideas on the handout or on a piece of paper in your notebook so that you can share them the next time we are together. If you have an experience you feel comfortable sharing, please write your responses down as well.*

Assign the exit ticket. Before they pack up and leave, ask students to get out a blank sheet of paper and respond to the prompts on the bottom of **slide H** as an exit ticket:

- *How do you think your community gets power? How is this different or the same as Texas?*

Students will need their responses for the beginning of next class.

End of day 1

5 · NAVIGATE: SHARE STORIES AND BROADEN TO RELATED PHENOMENA

10 min

MATERIALS: science notebook, *Collecting Stories*, chart paper for Related Phenomena poster, markers

Briefly orient students. Say, *We were talking about power outages in Texas, and we realized that we had a lot of stories of our own. I asked you to reach out to your families and communities for even more stories. I'm eager to hear what you learned, so let's get to it!* *

Conduct a round robin about the home learning. Organize students into groups of 3-4. Present **slide I** and briefly explain the structure of the round robin. Each student will have 2 minutes to share one of the stories they recorded when they spoke to their friends and family. They should keep *Collecting Stories* close to guide their discussion.

Reconsider the exit ticket. Next, the small groups should take a minute or 2 to discuss the questions they responded to as an exit ticket last time (shown on the second part of **slide I**), informed now by the additional funds of knowledge from their families and communities:

- How do you think your community gets power?
- How is this different or the same as Texas?

Brainstorm related phenomena in an Initial Ideas Discussion. * Bring the class back together and use **slide J** to solicit students' ideas in response to these questions:

- *Was a storm responsible for the blackouts you or your family experienced?*
- *What other phenomena could possibly cause a blackout?*

Keep a public record at the front of the room of students' suggestions in response to the second question. Title the list "Related Phenomena." You can do this on chart paper, a whiteboard, a projected document, or a transparency. * You may hear ideas such as:

- fires in California causing blackouts
- blackouts done purposefully to prevent fires
- hail or snow breaking wires
- squirrels, birds, or other animals chewing through or shorting wires
- wind blowing down electricity infrastructure
- fallen trees breaking or grounding wires
- running out of fuel, or something going wrong at a power plant

* ATTENDING TO EQUITY

Framing students' families and communities as legitimate funds of knowledge can serve multiple purposes. It can (1) help students feel like they belong in the science classroom by situating their family and community knowledge as productive resources for science, (2) engage students' families in conversations about what is happening in the classroom, and (3) help students make connections between the science classroom and their everyday lives.

* STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

For each discussion type, the teacher takes on a different stance in facilitation. Be explicit with students about your role in this discussion: to capture all student ideas, build excitement, and encourage as many students to participate as possible, whether their ideas are right or wrong.

Make space for all students to share their ideas (possibly connected to their experiences outside school, too). Encourage student-to-student talk with a focus on raising questions, clarifying, or adding onto what someone has said rather than a focus on debating or arguing. Students might also use head nods or hand signals to show they had a similar idea to a classmate's.

* ATTENDING TO EQUITY

Universal Design for Learning: In any Initial Ideas Discussion it is important to encourage students to draw from their own ideas and not worry about whether their ideas or questions are right or wrong. All ideas and questions are welcome. This provides students access by supporting student engagement.

6 · CREATE INITIAL MODELS AND CONDUCT A GALLERY WALK

15 min

MATERIALS: *Initial Models*, science notebook



Develop initial models. Present **slide K** and distribute *Initial Models*. Ask students to make a model that helps to show and explain blackouts, using the prompts on the handout, which you can read aloud:

1. Choose any two buildings in your community that have electricity. They can be close to each other or far apart. Model the system that brings power to those buildings.
2. Add to your model to explain why one building might get enough energy to power lights and devices while the other does not.

As students model, move around the classroom. Encourage them to show how the conditions are different in the parts of the community where there is a blackout (e.g., more trees to fall on power lines, power lines underground, a building closer to a hospital, older infrastructure).

Ask students to write answers to the questions at the bottom of the handout when they are finished modeling:

3. Where does the **energy** come from to power the electrical devices in each of those buildings?
4. What happens to the **energy** in this system that would have been used to power the electrical devices in each building during a blackout?

Allow 10 minutes for creating the models and answering the questions.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Modeling more than one system; for example, the power plant, the wires, and the houses. (SEP: 2.3)
- Indication of **energy transfer between systems**; for example, arrows connect systems, or the systems are drawn in a line, and/or the student indicates energy transfer in their written responses to questions 3 and/or 4 on *Initial Models*. (SEP: 2.3; DCI: PS3.A.2, PS3.B.4)
- Second model indicates a **clear change to the system**, and the repercussions of that change in terms of **energy transfer** (a blackout). (CCC: 7.1; DCI: PS3.B.2)

What to do:

- Support individual students by asking probing questions about how the energy transfers in their models, and then prompting them to show that. Use the language of stability and change by saying, *It looks like you modeled a stable system here. What changed in this second model to disrupt that stability?* If many students aren't modeling energy transfer through systems, or clear changes in their second model, it will be more difficult to come to consensus quickly on day 3, and you should consider budgeting an extra period for this lesson.
- If students are struggling to get started, invite them to begin recording questions they have that are making it hard to model. They can bring these to the Scientists Circle, even if they don't have a model yet.

Building toward: 1.A Develop a model of energy transfer through systems to explain how **energy manifests as electricity** in our communities, including **how changes to an otherwise stable system** could cause blackouts. (SEP: 2.3; CCC: 7.1; DCI: PS3.A.2, PS3.B.2, PS3.B.4)

Send students on a gallery walk. Present **slide L**. Have all students secure their models to a wall, or leave them open on their desks, and send them on a gallery walk. Each student should try to visit as many models as they can in 5 minutes, recording similarities and differences that they notice.

7 · DISCUSS COMMUNITY AGREEMENTS IN A SCIENTISTS CIRCLE

5 min

MATERIALS: science notebook, *Community Agreements*, Community Agreements poster

Form a Scientists Circle for the first time. Ask students to assemble their chairs in a circle and to bring their initial models and their notes from the gallery walk. Students will remain in the circle for all of class, though they will move among partner, small-group, and whole-class participation structures. This will help minimize the movement of chairs.

SCIENTISTS CIRCLE



You will form a Scientists Circle in many future lessons. If this is your first time, it is important to set up the agreements and logistics for forming, equitably participating in, and breaking down that space. As students get more comfortable with the Scientists Circle, they can move between it and other activity structures more quickly. Ideally, they will need to be able to see the slides and have access to a whiteboard, but if that is not possible, use only the whiteboard (or chart paper), which is where the more critical sensemaking will occur for the rest of the class.

Having students sit in a circle and face one another helps to build a sense of shared mission and community of learners working together. Returning to this Scientists Circle throughout the unit to take stock of what the class has figured out and where we need to go next will be an important tool in helping students take on greater agency in steering the direction of their learning. You may want to point out that collaborative consensus building is a fundamental part of what scientists do.

Introduce the idea of coming to consensus as a class. Tell students, *We had a lot of agreement across our models. We also had some competing ideas. Before we move on, we need to come to consensus around what we know and what we want to figure out.* The purpose of introducing the consensus task before talking about Community Agreements is to get students thinking about how difficult it will be to get all members of the learning community to agree, and how we want to make sure everyone is included and all voices are heard.

Introduce the science classroom Community Agreements. * Tell students that before the class moves on, it is time to think about how we want to work and learn together. Display **slide M** and distribute the handout *Community Agreements*. Read the four categories aloud. Ask students to turn and talk about the prompt on the slide for 1-2 minutes. Then, tell students that we are going to co-develop these agreements over the next few weeks, trying out new ideas about concrete actions we can agree to, and check in to see whether we are developing the culture we want to build—one that is respectful, equitable, committed to our community, and moving our science thinking forward.

Choose an agreement to work on today. * Present **slide N**. Say, *Today we were introduced to a puzzling phenomenon: a series of power outages in Texas. Our next task is to build an initial consensus model. We are going to have a lot of ideas on the table, and instead of just worrying about, "What do I think, and is it right?" we are going to put our ideas together and see whether we can figure things out together to move our science thinking forward.* (Point to this last category on the slide, or on the Community Agreements poster you prepared before class.)

Ask students to turn and talk about what it looks like, sounds like, or feels like to figure things out together as a community to move our science thinking forward. After a minute, elicit 1-2 ideas. Look for ideas about listening carefully to what our peers say, putting ourselves in our peers' shoes, keeping an open mind, and so forth. Keep track of 1-2 ideas that come up by writing them on the Community Agreements poster. You should focus on the "Moving our science thinking forward" and "Committed to our community" categories right now, but if students suggest something in another category, feel free to begin adding ideas to come back to.

ADDITIONAL GUIDANCE

If students struggle or are not ready to make suggestions, you can suggest the following: "We challenge ourselves to think in new ways" for the "Moving our science thinking forward" category, and "We come prepared to work toward a common goal" for the "Committed to our community" category. Ask students to turn and talk with a partner about what each of these might mean, and then elicit ideas from the class.

* ATTENDING TO EQUITY

One of the reasons that OpenSciEd uses the term "Community Agreements" is to highlight that there is not a "normal" way to collaborate. Developing norms is a powerful tool for equity in the classroom when done collaboratively and thoughtfully. But be aware that ideas such as *safe, respectful, polite, nice, and kind* are culturally embedded, and thus can mean different things in different communities. For example, one student may define kindness as not calling out a peer in public when they say something offensive. But another student may define kindness as being honest with peers, and sharing what is on their mind and heart right away. Whose version of kindness receives priority? When these ideas are not explored, norms can be used to police or silence justifiable hurt and anger, particularly from students who identify with marginalized communities. For examples of inclusive Community Agreements that support equitable spaces, visit <https://www.theequitylab.org/blog/why-start-with-agreements>.

* ATTENDING TO EQUITY

Universal Design for Learning: It is important to use the Community Agreements to cultivate an equitable learning community that promotes trusting and caring relationships that foster student *engagement*. The agreements should remind students to value the diversity of classroom community members and equity in the sensemaking work they will do together. It is critical that the agreements support safe and fair participation and interrupt cultural norms or stereotypes that could make science experiences feel uncomfortable to students.

8 · COME TO CONSENSUS IN A SCIENTISTS CIRCLE

15 min

MATERIALS: *Progress Tracker*, chart paper for Initial Consensus Energy Transfer Model poster, markers, sticky notes (3x3)

Sketch the relevant systems and/or components that we agree on. Present slide O. Ask students to share subsystems or parts of systems that they saw in common across several models during the gallery walk. * Use the prompts below to elicit important subsystems and interactions. Sketch the systems and parts that students name on chart paper at the front of the classroom. * Title this poster "Initial Consensus Energy Transfer Model"

Suggested prompt	Sample student response
<i>What were some of the subsystems or components that you saw in common across all or most of the models during the gallery walk?</i>	We saw fuel, turbines, power plants, electrical lines or wires, transformers, houses or buildings, and devices.
<i>What differences did you notice between the subsystems and components in the models during the gallery walk?</i>	Some systems had fuel, some had a turbine, and some had nothing in the power plant. Some systems included lots of houses, some did not. Some people had a source and a power plant, some people just drew a power plant.

Your sketch may initially include representational images of power lines and other structures, and this is fine. Aim to include at minimum three connected subsystems. These will most likely be either a power plant or an energy source, power lines, and then either houses or devices. Add question marks to the parts of the system where there was disagreement or where the class wasn't sure about something.

Introduce the words *grid* and *subsystem*. Point out to students that the system we have represented here as a whole is often referred to as "the grid." Ask students whether they have seen that word before. Some students may say they encountered it in their readings, or heard it from their parents. Say, *We call this whole system the grid. Let's see if we can identify some of the systems that make up this system. Sometimes scientists and engineers call systems that make up other systems subsystems.* *

Isolate 2-4 systems through which energy transfers. Present slide P. Spend some time helping students simplify into systems with subsystems. Say, *I don't think everyone included all of the same electrical structures. But would you agree that everyone included some set of structures with wires to transfer energy from the source to the community?*

Using a new color or thickness of marker, draw a dotted line on the initial consensus model to bound the transmission system (constituting the electrical wires and related infrastructure). Do the same around the destination subsystem and the source subsystem. If students have made a distinction between the source and the power plant, you can distinguish between these subsystems as well.

KEY IDEAS

Purpose of the discussion: To generate a variety of initial ideas about how energy transfers into the devices we use everyday, and what could cause instability in the system.

Listen for these ideas:

- Energy transfers from a source, through wires or other structures, to our communities.
- Though we may not agree on what all the structures are, we agree at least on three general systems: (1) some kind of source (e.g., power plant), (2) some kind of transmission structure (e.g., power lines), and (3) a destination (e.g., buildings in our community).

* SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

A high school understanding of systems goes beyond systems made up of interacting subsystems. In this unit, students will define a system's boundaries and initial conditions, as well as its inputs and outputs. Students will use computer models to simulate the transfer of energy and interactions within and between systems when the system is stable, and to predict the behavior of the system when it changes. Finally, they will design systems to do a task as part of the engineering design challenge built into the unit.

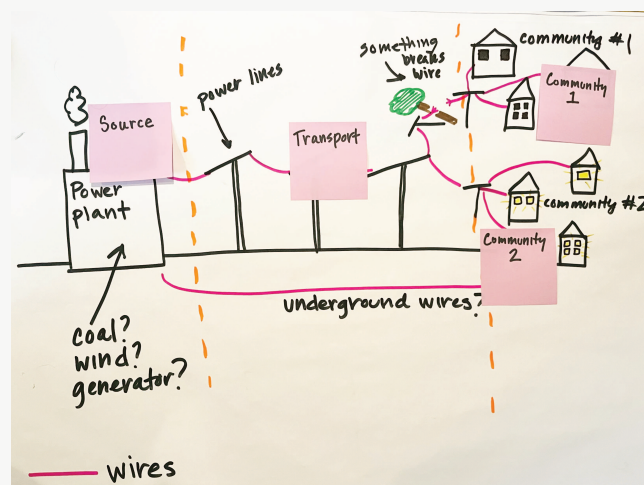
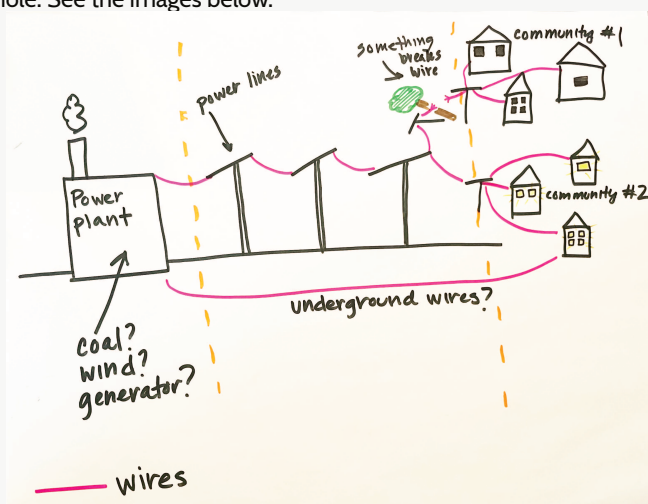
* ATTENDING TO EQUITY

Universal Design for Learning: Use *representations* like color coding and/or letter or number coding to foreground parts of the model. Create a key to track what colors, symbols, or codes represent different parts of the system. Though color coding is useful for quick reference, letter or number coding helps ensure accessibility for any student who may be color-blind. If color coding is used, consider a color palette with orange, blue, black, or dark brown.

* ATTENDING TO EQUITY

Supporting emergent multilinguals: Allow and encourage students to talk about their ideas using both content-specific and everyday words and phrases. This helps students fully express themselves, allowing others to question, evaluate, and build off their ideas. Switching back and forth between different registers is especially important for emergent multilingual students because it helps them draw on their full range of sensemaking resources.

Add sticky notes to represent systems. This step is very important to help students move from diagrams that focus on matter toward more abstract energy transfer representations. Ask students what to label these 3-4 systems, soliciting buy-in from the class when a term is suggested, and then use these terms on sticky notes to label the model. Point out that systems can have multiple subsystems or components, and that we are bounding our subsystems based on the role they play in getting energy to buildings as part of the system as a whole. See the images below.



* SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE

In high school, students are expected to dig deeper into constructing explanations of how things change and how they remain stable. This model is an opportunity for students to start thinking about how systems can be designed for greater or lesser stability. They may also begin to notice that some system changes are irreversible (e.g., a broken power line), while others are temporary (e.g., a frozen gas line). Throughout the rest of the unit, students will explore the ways in which feedback can stabilize or destabilize our electrical system, and how rates of change can be quantified and modeled over very short or very long periods of time.

Add energy transfer and other interactions to the model. Ask students to share interactions between these systems or parts of systems that they saw in common.

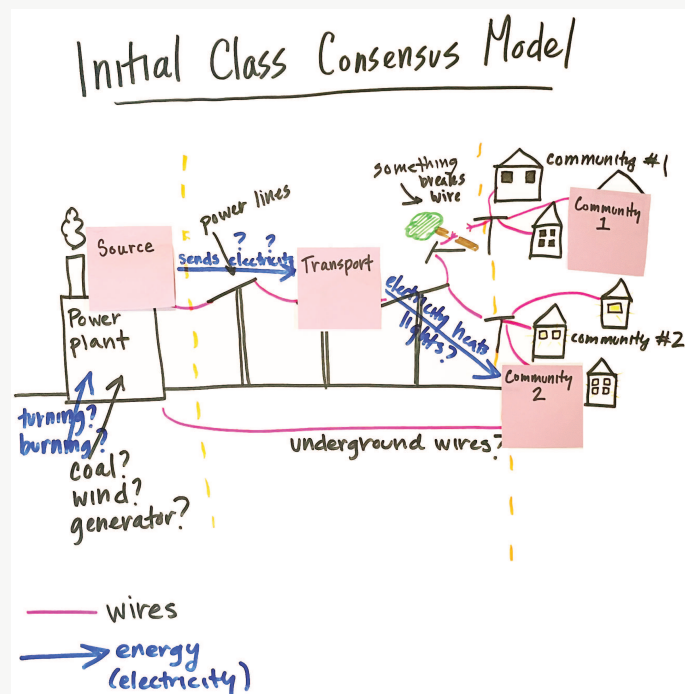
Suggested prompts	Sample student responses	Follow-up questions
<i>Let's start at the energy source. How is energy being transferred here?</i>	burning or turning electricity moving heat energy transfer or moving movement of charged particles (or electrons)	<i>What motions and interactions did you see that could have caused this energy transfer?</i>
<i>How is energy being transferred in the next system?</i>	electricity moving or flowing energy transfer or moving movement of charged particles (or electrons)	<i>What motions and interactions did you see that could have caused this energy transfer? How about the next system after that?</i>
<i>What differences did you notice between the way energy transfer was represented in the models during the gallery walk?</i>	something burning in some systems, something turning in others, nothing at all in others particles moving through the wire in some systems, energy in some, electricity in some heat involved in some systems, no heat in others	
<i>So far we have talked mostly about the system when it is stable. What were some of the ways that you noticed people representing change to the system that could have caused a blackout? *</i>	power lines broken power sources disconnected or not working	

In a new, bright color, sketch arrows between the sticky notes in the model to represent energy transfer from one system to the next, using the interactions suggested by students. Continue to add question marks where we still have questions or don't agree on something. Say, *This is really a diagram showing how energy transfers between these systems*. The initial representations of buildings, power lines, and the like should fade into the background, and the stickies and arrows should stand out. Your finished model may look something like the example below.

Introduce and add to *Progress Tracker*. Present **slide Q** and distribute *Progress Tracker*. Explain that throughout this course, we will be keeping track of our thinking using a *Progress Tracker*. Explain that the tracker is not intended to be a record of the "right" answers--it is a record of our changing thinking over the course of a unit, and should be a place where students feel comfortable reflecting on what they do not know or do not yet understand. Tell students to copy the sticky-note systems and energy transfer arrows/descriptions into their *Progress Tracker*. Tell them they do not need to include the buildings and infrastructure in their models.

Ask, *What question are we trying to answer with this model?* Solicit 2-3 ideas, and then ask students to write the question they feel we are trying to answer right now, sideways in the box marked “Lesson” in the *Progress Tracker*.

Finally, ask students to think about what we did to figure this out. They may suggest that we drew on our experience and what we know already. They might also say that we made models and compared them to others’ models. There isn’t a lot we know right now, and that’s OK. Have students record something in the far right column of the tracker that reflects this conversation.



ADDITIONAL GUIDANCE

Progress Tracker is a formative self-assessment tool that is designed to help students keep track of important discoveries that the class makes while investigating phenomena, and to help them figure out how to prioritize and use those discoveries to explain the phenomenon they’re working on. The *Progress Tracker* is a metacognitive tool requiring students to (1) look back at what we have done, (2) make decisions about where we are going next, and (3) consider what we don’t know. Metacognitive strategies like these support students in deepening learning and building agency (Bransford, Brown, & Cocking, 2000; Zohar & Barzilai, 2013). Students will refer back to the tracker regularly to revise or build on their models, explanations, and/or designs that reflect their current thinking about the phenomenon. The *Progress Tracker* is not intended as something to be graded and will be used in this unit as an informal place for individual student sensemaking. Students will shift to formally using the Engineering Design Tracker in Lesson 3, and will continue using it for the rest of the unit but may still process their science thinking in the *Progress Tracker*.

End of day 2

9 · NAVIGATE: TEST OUR MODEL IN TEXAS

10 min

MATERIALS: Initial Consensus Energy Transfer Model poster, chart paper for Ideas for Data/Investigations We Need poster, markers

Turn and talk about Texas. Present **slide R**. Point to the model we developed last time and give students a moment to study it. Have students turn and talk about the prompts on the slide:

- Can you use the class's Initial Consensus Energy Transfer Model to explain the pattern of power outages we noticed in Texas in February 2021?
- What additional data or information would we need in order to explain these patterns?

Give students 2-3 minutes to discuss these prompts.

Make a public record of our ideas for data. Ask student pairs to share what they discussed, and solicit reactions from peers. Keep a public record of students' ideas on a piece of chart paper titled "Ideas for Data/Investigations We Need." You will come back to this poster and add to it after the class creates the Driving Question Board (DQB).

10 · BUILD THE DQB

20 min

MATERIALS: sticky notes (3x3), black markers, *Texas Outages Map*, DQB Student Reference handout (optional), Related Phenomena poster, Initial Consensus Energy Transfer Model poster, DQB

Write initial questions for the DQB. Make sure the class's Related Phenomena poster and Initial Consensus Energy Transfer Model poster are located at the front of the room where students can see them. Distribute 3-4 sticky notes and a dark-colored marker to each student. Present **slide S**. Say, *On a sticky note, write at least one question that you have about blackouts and generating power. Only one question per sticky, please, and don't forget to add your initials so that we know who contributed a question.*

Gather in a Scientists Circle around the DQB. Instruct students to bring their sticky notes with completed questions along with their science notebooks and chairs to meet in a Scientists Circle around the DQB.

Support students in building the DQB. Present **slide T** and/or distribute the DQB Student Reference handout.

ADDITIONAL GUIDANCE

If students have questions that are related to the system as a whole, or to energy transfer more generally, and are not sure where to put them, ask the class to weigh in with ideas. Most likely, students will decide to put these broader questions above the model, or in a corner of the poster.



Explain that you would like students to take the lead on this process. You might want to choose the first volunteer to begin the process and then step back. Students should use the directions on **slide T** and/or the handout to guide them. Step in when necessary to point students to the class's agreements to encourage equitable participation. The student-facing directions for assembling the DQB are:

1. Choose a volunteer to go first. This student reads their question and puts it on the DQB.
2. Raise your hand if you have a question that is related or the same. The first volunteer selects the next student whose hand is raised. The student who is called on reads their related question, says why or how it relates, and then moves it onto the DQB with the original question.
3. Repeat step 2 until the class agrees that all related questions are up. Then go back to step 1, and choose a volunteer with a different question to start a new cluster. Continue until everyone has shared 1-3 questions.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Questions about specific systems, for example the power plant, the wires, the building. (SEP: 1.4)
- Questions that go beyond mechanistic explanations (e.g., “How does a generator work?”) to explore design challenges and tradeoffs (e.g., “How can we prevent something like Texas in our community?” and “How can we make energy production more green?”). (SEP: 1.4; CCC: 4.1)
- Questions that define specific local or global challenges that students either noticed in the anchor or bring from their own experience (e.g., pollution, job creation, disparities in electricity access). (SEP: 1.8; DCI: ETS1.A.2)

What to do: Slide R foreshadows the design challenge woven throughout this unit. Consider making another pass at the DQB after this brainstorm, when students are thinking more directly about engineering design for their community.

Building toward: 1.B Ask questions to clarify and define the problem of how our community can generate energy by designing systems to address both local and global challenges. (SEP: 1.4; 1.8; DCI: ETS1.A.2; CCC: 4.1)

11 · BRAINSTORM DESIGNS AND FURTHER INVESTIGATION

10 min

MATERIALS: Ideas and Investigations We Need poster, markers

Introduce the design challenge. Say, *Whether or not we live in Texas, power is a huge part of our lives. How do you think that answering some of these questions might help us make decisions in our own communities?* Accept all ideas.

Say, *We have a lot of questions about what happened in Texas. We also have a lot of questions that are more general, and could help us design solutions for our own communities and other communities around the world.* Pick out 2–3 questions on the DQB that are related to local and/or global systems and point to them now.

Name the DQB. Ask, *Can we articulate a question that we will be answering by investigating all of these questions?* Listen for ideas like, “How could we design better electricity to meet our communities’ needs?” or “How can we make sure what happens in Texas doesn’t happen where we live?” If the questions students suggest at first are too focused on Texas, remind them that we have a lot of questions about our own communities.

Ask, *Do you think that by answering this question, we will get to most of the questions on our Driving Question Board?* Look for agreement from students, and then write this question at the top of the DQB.

Brainstorm additional data and investigations. ✱ Present slide U. Tell students that after we figure out what happened in Texas, we will apply those ideas to articulate some solutions we want to advocate for in our own communities. Ask students to share their ideas about the questions on the slide:

1. *What are some things you would want to learn about what happened in Texas to inform and refine your community solutions?*
2. *What sorts of investigations could we carry out within our own class to further advance our understanding, and answer more of our DQB questions?*

If there is time, give them a minute to turn and talk with someone else before sharing as a whole class. Record student ideas on the poster you began earlier, Ideas for Data/Investigations We Need.

✱ STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

Use talk strategies to draw out a variety of ideas from a larger pool of students. If it feels like students don’t have any more ideas, don’t move on right away. Instead, count to ten in your head to give them more time to consider. Use questions to push their thinking to new contexts and provide more opportunities for them to make connections to their experiences. For example, if students are only talking about data from Texas, say, *We definitely want to investigate the context around what happened in Texas to inform our ideas. Are there any investigations we could do here in the classroom to answer some of our questions that are about energy production more broadly?*

MATERIALS: science notebook

Reflect on the anchor experience. Present **slide V**. Ask students to stop and jot about one of the prompts on the slide:

- *How did it feel to make a model of something you hadn't explicitly learned about yet?*
- *How did it feel to ask questions in science class and not get the answers right away?*
- *How did it feel to set community agreements?*

Reassure students that phenomenon-based instruction is different and new, and that we are figuring it out together.



Assign a self-documentation task for home learning. ✱ Say, *We have a lot of ideas and places where we can start. We can jump into these next time. In the meantime, let's see what we can learn just by noticing the stuff around us that we think is part of the systems that bring electricity into our homes. Maybe we will see some patterns that could help us understand how the systems work, and identify important design constraints.*

Present **slide W**. Say, *Observe the electricity infrastructure that you see at school, at home, on your way to and from school, and anywhere else you go. Make a record of what you see, either by taking photos or making a sketch. This may include wires, outlets, or anything else you see that might be related. Send your photos and sketches to me, or bring them with you for the next time we meet.*

Set up students' Personal Glossaries and add an entry. Tell students to add a divider at the end of their notebooks, and insert a piece of paper after the divider. This will be their Personal Glossary. Have them add the word *infrastructure* to their glossary, and then use students' ideas to develop a definition as a class. It may look something like this: "The physical structures that we need for our society to work, such as buildings, roads, and power supplies." Then give students a moment to add any additional words they have co-constructed or encountered in this lesson, such as *grid*, *subsystem*, or *electricity*.

✱ ATTENDING TO EQUITY

Self-documentation is a formative assessment strategy to surface the dynamic, everyday practices and concerns in the students' communities that can be meaningfully related to classroom science and engineering investigations.

Some students may not have access to a camera, so make sure that no one in the class is put on the spot. Ask students to send you their contributions ahead of time, and curate them before class in a slideshow or by printing them out and putting them on a poster. You can also give the option of using a pen and paper to draw their observations. For more about self-documentation, see <http://stemteachingtools.org/sp/self-doc>.

Additional Lesson 1 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

There is a Common Core ELA standard that is targeted in this lesson.

- **CCSS.ELA-LITERACY.RST.11-12.2** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Students read a series of articles about blackouts in Texas in February, 2021. They use a jigsaw structure to summarize their articles for their peers by paraphrasing them.

LESSON 2: What structures in the system enable energy transfer from one source to multiple devices, buildings, and neighborhoods?

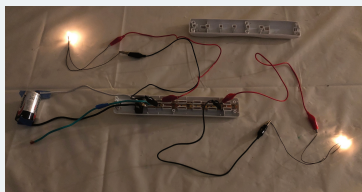
PREVIOUS LESSON

We explored widespread blackouts in Texas. We modeled our electricity production system. We developed questions and brainstormed how we could design more reliable systems to meet our communities' energy needs. We decided to document the electricity infrastructure in our homes and communities to look for patterns that could help us understand how the system works.

THIS LESSON

INVESTIGATION

2 days



We compared photos and drawings of structures that provide electricity in our buildings and neighborhoods. We dissected a power strip and connected it to a battery to power multiple devices. We read about the function of ground wires and circuit breakers. We developed a model of how structures of the power strip system enable it to transfer energy from one source to multiple devices. We used this model to draw parallels to larger-scale systems (buildings, neighborhoods) and test the effects of short circuits and broken circuits.

NEXT LESSON

We will read about an energy crisis that began in Ohio, and a strategy used by engineers to prevent short and broken circuits in power lines. We will keep track of our ideas in the Engineering Design Tracker. We will develop a new representation to model energy transfer through parts of the system. We will analyze electricity demand and supply data in Texas and use this to brainstorm ideas of where to go next.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

2.A Collect data from a designed system (a power strip) and a network of interconnected subsystems (multiple powerstrips) on the interactions needed for and failure points in the transfer of electrical energy. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1)

2.B Develop, revise, and use a model to identify analogous structures that affect the electrical energy transfers across and between different (sub)systems at different scales (a powerstrip versus a building). (SEP: 2.3; DCI: PS3.B.2; CCC: 4.1, 6.1)

WHAT STUDENTS WILL FIGURE OUT

- Energy will transfer from a source to a device when a complete circuit is formed, but it will stop transferring immediately when there is a break in any of those paths (a broken circuit).
- Plugging in an electronic device creates a giant circuit from that device to a power source that may be far away.
- When energy transfers through a circuit system without powering any devices, we call this a short circuit. A short circuit occurs when there is a direct conducting path from one side of the energy source to the ground or to the other side of the source. A single short circuit in a system can cause blackouts in the entire system.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		NAVIGATE Share what we took photos of and what we noticed.	A	home learning artifacts from Lesson 1
2	4 min		IDENTIFY IMPORTANT SAFETY PRECAUTIONS Identify important safety precautions and safer sources of energy we could use.	B	Safety glasses with side shields or safety goggles, Safety poster
3	8 min		DISSECT A POWER STRIP Carry out Investigation A to dissect a power strip in groups.	C-D	<i>Power Strip Model</i> , Dissection (Investigation A)
4	10 min		POWER THE CIRCUIT Connect a single light bulb to a battery using the dissected power strip as an intermediate structure in the system. Connect multiple light bulbs and/or a motor to the power strip system and provide them with electrical energy.	E-G	Powered Circuit (Investigation B)
5	12 min		DEVELOP A MODEL FOR EXPLAINING HOW THE POWER STRIP SYSTEM WORKS Guide students in developing individual models for explaining how the parts of the power strip system are connected to transfer energy to devices. Collect the models for assessment.	H	<i>Power Strip Model</i> , whiteboard or piece of chart paper (optional)
6	5 min		CLEAN UP AND ASSIGN HOME LEARNING Clean up from the lab. Orient students to the goal of the home learning reading assignment.	I-K	<i>Electricity Related Parts</i> , <i>Power Strip Model</i> , Investigation A supplies, Investigation B supplies
End of day 1					
7	5 min		NAVIGATE AND SHARE NEW IDEAS Navigate into the day and share new ideas from the home learning.	L	<i>Electricity Related Parts</i>
8	12 min		DEVELOP A CLASS CONSENSUS MODEL FOR HOW THE POWER STRIP SYSTEM WORKS Develop a class consensus model to represent how the structure of the power strip gets electricity to multiple devices from a single source.	M	<i>Power Strip Model</i> , colored markers (blue, red, and green), tape, blank paper (half sheet), Power Strip and Battery System Model poster, piece of blue yarn, piece of red yarn, Powered Object cards, Switch Description card
9	8 min		DEVELOP A MODEL FOR CIRCUITS IN A BUILDING Develop a model to represent structures in a building that are analogous to those in the power strip system. Use it to explain how energy is transferred to multiple devices in a building.	N-T	Power Strip and Battery System Model poster

Part	Duration	Summary	Slide	Materials
10	7 min	USE THE POWER STRIP MODELS TO INVESTIGATE ELECTRICAL DISTRIBUTION IN A CITY Test that the light bulbs in each building system will turn on when they are hooked up to a battery. Combine all groups' buildings into one model "city" hooked up to a single power source and conduct an investigation.	U-V	Electrical Distribution in a City (Investigation C)
11	6 min	USE THE MODEL CITY TO INVESTIGATE POWER OUTAGES FROM SHORT CIRCUITS AND BROKEN CIRCUITS Conduct an investigation with the model city to simulate the effects of short circuits and broken circuits.	W-Y	
12	3 min	ADD TO OUR COMMUNITY AGREEMENTS Reflect on our progress in "Moving our science thinking forward", and add Community Agreements to the "Equitable" and "Respectful" categories.	Z	<i>Community Agreements</i> , Community Agreements poster from Lesson 1
13	4 min	NAVIGATE Raise new ideas and questions about the Texas case study.	AA	sticky notes, markers

End of day 2

Lesson 2 • Materials List

	per student	per group	per class
Dissection (Investigation A) materials		- power strip - Phillips screwdriver	
Powered Circuit (Investigation B) materials	<i>Power Strip Model</i>	- D battery - tape 4 incandescent grain-of-wheat light bulbs (1.5V 100mA) 8 alligator clips 2 additional alligator clips with one end stripped to tape to the battery - power strip - Phillips screwdriver	- D battery - tape 1 incandescent grain-of-wheat light bulbs (1.5V 100mA) 2 half alligator clips with ends stripped to tape to the battery
Electrical Distribution in a City (Investigation C) materials		- D battery - tape 2 incandescent grain-of-wheat light bulbs (1.5V 100mA) attached to a dissected power strip and this nested inside a building model 4 additional alligator clips	- dissected power strip 18 alligator clips 2 additional alligator clips with one end stripped to tape to the D battery - tape - tented sheets of paper labeled “Electrical energy source” and “Substation”
Lesson materials	- home learning artifacts from Lesson 1 - Safety glasses with side shields or safety goggles <i>Power Strip Model</i> - science notebook <i>Electricity Related Parts</i> <i>Community Agreements</i>	- Investigation A supplies - Investigation B supplies - colored markers (blue and red and green) - tape - blank paper (half sheet) - Power Strip and Battery System Model poster - piece of blue yarn - piece of red yarn - Powered Object cards - Switch Description card	- Safety poster - whiteboard or piece of chart paper (optional) - Power Strip and Battery System Model poster - Community Agreements poster from Lesson 1 - sticky notes - markers

Materials preparation (90 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Prepare a Safety poster with this principle written on it:

- Individually and as a class, we have an ethical responsibility to consider the possible personal, societal, and environmental impacts of any scientific investigation we plan or engineering solution we design.

Use colored markers (blue, red, and green) to prepare the Power Strip and Battery System Model poster as shown here.

Make a rotatable switch to add to the poster. On half an index card, draw a thick blue line from one corner to another. Hole-punch one corner and hole-punch the poster on one side of the gap in its blue line. Insert a brad fastener through the card and poster as shown below. This will allow the card to pivot back and forth. Lightly tape the switch into an open or closed position.

Gather 4 pieces of 8" long blue yarn and 4 pieces of 8" long red yarn.

Prepare 3 Electricity-Powered Object cards as follows:

- Draw a light bulb on blank paper (half sheet). Tape 1 end of a red piece of yarn and 1 end of a blue piece of yarn to the bottom of the light bulb.
- Repeat this 2 more times.

Attach all of these pieces to the edges of the poster with tape. Later in the lesson, you will move Powered Object cards to new locations on the poster and then remove them between classes.

You will tape the remaining 2 pieces of yarn to the poster later in the lesson.

Write a Switch Description card describing the role of the switch as shown, and set it to the side.

Write a card with the word "Ground" in green pen, and set it to the side.

Later in the lesson, you will add these two cards to the poster and then remove them between classes.

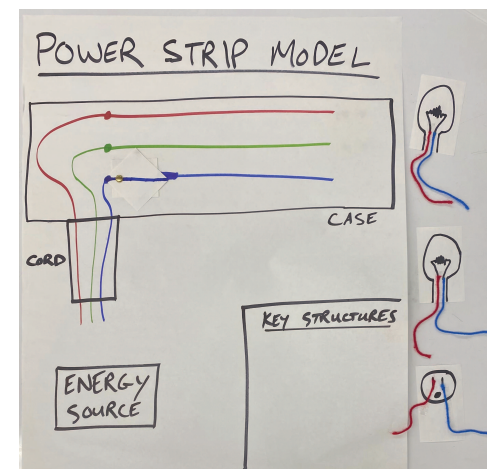
Set aside some blank sheets of paper to add annotations to the poster (with tape), including one to record "Key Structures". At the end of the period on day 1, remove all the items taped to the poster in preparation for the next class; but at the end of the last period on day 1, leave them taped to the poster so they are there as reference for all classes at the start of day 2.

SAFETY PRECAUTIONS

1. Wear sanitized safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of activities.
2. Use caution when using sharp (tools, wires, etc.), which can cut or puncture skin.
3. Keep away from water sources to prevent shock when working with electrical circuits or electricity sources.
4. If the battery or wires overheat, disconnect the circuit to prevent skin burns or fire.
5. Do not use lithium-ion batteries - they are a fire hazard!
6. If the battery is leaking or has residue on it, do not use it.
7. Never stand directly in front of a circuit breaker enclosure when throwing a breaker/switch. If there is an arc-flash, you want to be as safe as possible.
8. Before working with the power strip, make sure the plug has been completely removed and disposed of safely, so that it cannot be connected to an electrical receptacle. If it is connected to an electrical receptacle there is risk of an electrical shock!
9. Use caution when working with glass bulbs. If a bulb shatters, the pieces of glassware are sharp and can cut hands.
10. Make sure all materials and equipment are returned to the appropriate location upon completing activities.
11. Do not reuse dissected and reassembled power strips for anything other than labs in this lesson.
12. Wash your hands with soap and water immediately after completing this activity.

Of the four investigations (A, B, C, D), three build on supplies used in the prior lab:

- B uses new supplies along with those from A.
- C uses new supplies along with those from A and B, but with only a single light bulb connected to each power strip.
- D uses the same supplies as C.



*closed switch provides a
2nd unbroken metal path
so energy can transfer*

Day 1:

Dissection (Investigation A)

- **Group size:** 3 students
- **Setup:**
 - For each group:
 - Use a wire cutter to cut the cord of a power strip about an inch from the plug. Dispose of the plug someplace where nobody can access it accidentally. **Plugging this into the wall could result in injury or death.**
 - Use a wire stripper to carefully remove the white insulation from the first couple of inches of the cord. Then use the wire stripper to remove about half an inch of insulation from each of the 3 wires inside, exposing the copper wires within.
 - As a safety feature, some power strips have a single triangle-head screw (TA20)--remove this with a triangle-head screwdriver (turning counterclockwise) and dispose of it. Alternatively, you can snap the plastic column connecting the 2 sides of the power strip. Wear safety goggles as you pull the sides apart to avoid injury from small pieces of plastic that may fly off.
 - Loosen the 5 Phillips screws on the back of the power strip with a Phillips screwdriver (turning counterclockwise). Remove all but 2 of the screws to make dissection and reassembly faster for students. Save the extra screws in case any get lost.
 - Some power strips may have a "surge protector" circuit built into the switch assembly. Understanding how this circuit functions is beyond the scope of this unit, and leaving it in the power strip can make it difficult to see the important structures. This is why the powerstrips you are using in the kit provided with this unit do not have any in them.
 - Place all the related materials in a tote or other bin marked with tape as "A".
- **Storage:** All materials can be stored and reused (only for labs A-D in this lesson) indefinitely.



Powered Circuit (Investigation B)

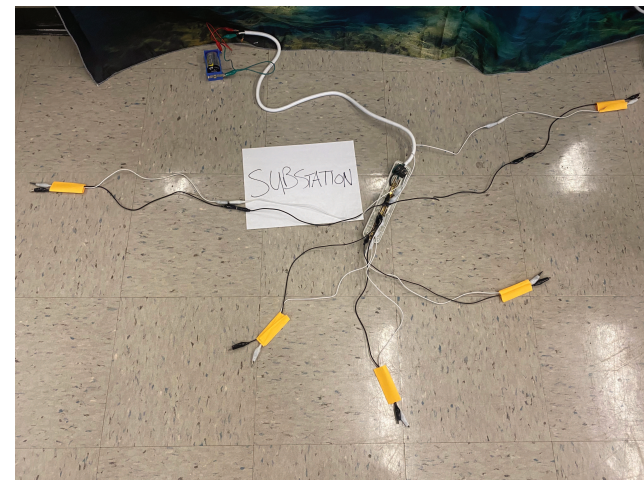
- **Group size:** 4 students
- **Setup:**
 - For each group:
 - Cut off the ends of 2 alligator clips for each group, and strip off about a half inch. This will make it easier for students to attach them to a battery.
 - Strip about a half inch off the end of the wires attached to 4 incandescent grain-of-wheat light bulbs (1.5V 100mA) to connect the alligator clips to them.
 - Add all of these and 8 more unstripped alligator clips, a D battery, and tape into a tote or other bin marked with tape as "B".
 - For an additional control condition to refer to as a class:
 - Add 2 alligator clips with 1 end clipped and stripped, tape, a D battery, and 1 incandescent grain-of-wheat light bulb (1.5V 100mA).
 - At the end of the period, students will reassemble the power strip for the next class. Ask your last class to keep the power strip disassembled and only 1 of the light bulbs attached to it. This will simplify preparing the materials for Investigation C.
- **Safety:**
 - Keep these materials away from electrical sockets!
 - Do not reuse these dissected and reassembled power strips for anything other than labs A-D in this lesson.
 - Short-circuiting any part of the circuit will cause the battery to heat up quickly. Carefully feel the battery to ensure this isn't happening.
- **Storage:** All materials can be stored and reused indefinitely.

Day 2:

Electrical Distribution in a City (Investigation C)

- **Group size:** 4 students
- **Setup**
 - For each group:
 - Set aside a few sheets of paper that each group will fold in half and label and/or decorate to indicate a "building" in the community.
 - Place a dissected power strip with an incandescent grain-of-wheat light bulb (1.5V 100mA) attached.
 - Test that the light bulb(s) turns on by connecting the 2 ends of the power strip to a D battery.
 - Optional: For a more tangible representation of buildings in the model city, prepare a cardboard building structure for every group in your largest class. See *Preparing Cardboard Buildings* for directions.
- **Set up a demonstration area in an area separate from students' tables--a square approximately 4-6 feet on a side.**

- For the city's electrical energy source, hook a single D battery up to the black and white wires of the dissected power strip. Make sure the plug is cut off the end of the power strip and the wires are stripped (not shown in the photo here).
- Hook enough pairs of alligator clips to the strip to provide access points for groups to plug their building into, using extra alligator clips if needed. If possible, route the extra alligator clips a few feet away from the battery in multiple directions, to allow space for all buildings to connect easily. (Assume a square 4-6 feet on a side = 16-36 square feet of total space.)
- Make sure the switch is turned off and no ends of wires are touching.
- Label tented sheets of paper as follows:
 - Substation
 - Electrical energy source (power plant)
- Place these at the corresponding locations in the system.
- **Safety:**
 - Keep these materials away from electrical sockets!
 - Do not ever reuse these dissected and reassembled power strips for anything other than labs A-D in this lesson.
 - Short-circuiting any part of the circuit will cause the battery to heat up quickly. Carefully feel the battery to ensure this isn't happening.
- **Storage:** All materials can be stored and reused indefinitely.



Power Outages from Short Circuits and Broken Circuits (Investigation D)

- **Group size:** Whole class
- **Setup:**
 - This investigation uses mostly the same materials as Investigation C, but with only a single light bulb connected to each power strip.
 - You will also use a large paper clip (or pair of scissors) to cause an "accidental" short circuit. This should not be a wire, because a wire implies an intentional connection.
- **Safety:**
 - Keep these materials away from electrical sockets!
 - Do not ever reuse these dissected and reassembled power strips for anything other than labs A-D in this lesson.
 - Short-circuiting any part of the circuit will cause the battery to heat up quickly. Doing this at least once is important to demonstrate the effect that a short circuit has on a city, but take steps to make sure the battery doesn't stay shorted for long.
- **Storage:** All materials can be stored and reused indefinitely.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

This lesson builds a foundation for the rest of the unit, using several elementary and middle school grade band ideas that are established quickly, and also using high school level practices and crosscutting concepts. According to pilot testing, ideas about circuits developed in this lesson do not tend to show up on students' initial models created in the prior lesson, so it is essential that they be redeveloped and added before moving on to high school level ideas about energy transfer. The lesson reinforces and builds on the elementary grade band idea that energy can be transferred through circuits, and that a circuit is a structure that provides a continuous loop for a current to follow.

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS3.A.3** “Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents.
- **PS3.B.2** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.

Note: We want to avoid any inaccurate assumptions about why two wires are required between an energy source and an electricity-powered object, while building toward an understanding of electric current later in the unit. In the next lesson, we will build an energy model of this same system and highlight the differences between this model and our “circuit diagram.”

The lesson helps students recognize that similar structures enable energy transfer from an energy source to multiple devices, in systems at a variety of scales (power strips, building, neighborhoods) in modern electrical grids that serve our communities. This is a part of developing high school level ideas related to ETS2 (Influence of Engineering, Technology, and Science on Society and the Natural World).

The model developed on day 2 of the lesson represents a continuous path of wire between an energy source, a substation, and buildings in a neighborhood. This is a useful assumption for the model and is required for understanding the need for complete circuits in order to transfer energy across most parts of the electrical grid. In reality, substations and other points in the electrical grid contain transformers, which induce an electric current in physically separate circuits to increase or decrease the voltage. These are points at which there is a physical gap between one circuit and another. However, this nuance is not a necessary understanding for this unit.

The energy source in this investigation, a battery, is a stand-in for other energy sources in the electrical power grid that students will uncover in later lessons (e.g., turbines driven by wind, heated steam, burning coal or natural gas, and so forth).

Students will encounter or co-develop definitions for the following terms in this lesson: *circuit, switch, ground, substation, short circuit*. **Do not** post any words or ask students to add them to their Personal Glossaries until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

In this lesson, we are not explicitly discussing mechanisms for energy transfer or matter transfer. The models we develop only ask students to consider what connections make that energy transfer possible. In subsequent lessons (L3 and L5), we will refine our model using two separate representations for energy transfer across the system (in L3) and matter flow at a particle level (in L5). Going too deep into energy transfer is not the goal of Lesson 2. Avoid dwelling on this aspect of the system for now, as it will likely reinforce in students an incorrect mental model of matter transferring from battery to bulbs through **two** wires.

We will introduce the terms *current* and *voltage* in Lesson 5. It is important that students earn these words **after** investigating the way that electrical energy transfers due to the flow of electrons through a wire.

This is also not a lesson about parallel versus series circuits. Students will review and apply middle school ideas about electricity and circuits, but only to provide (1) a context for high school level ideas about energy conservation and transfer and (2) a complex and authentic design challenge with both local and global implications.

This lesson does not explain how or why most houses and businesses in the United States have three separate electrical lines going to them in addition to a grounding wire. In those cases, there are AC currents in two wires, one of which is out of phase with the AC current in one of the other wires. This provides buildings a higher net voltage than the standard 120-volt circuits. The higher voltage enables larger loads (especially electric ovens) to be powered with less current. As this lesson does not introduce *voltage* or *current*, avoid this complication, because most electrical sockets in residences have only two electrical wires with a 120-volt difference, and a third grounding wire. Nonresidential buildings may have even higher voltage feed lines.

This lesson does not distinguish a circuit breaker from a surge protector or a fuse. Though it does introduce the idea that these devices detect and respond to a power surge and automatically shut off or break the circuit by “tripping” an on/off switch, it doesn’t provide an explanation or a detailed mechanism for how this happens within them.

LEARNING PLAN for LESSON 2

1 · NAVIGATE

6 min

MATERIALS: home learning artifacts from Lesson 1

Introduce the purpose of the navigation routine. Show slide A and say, *Last time, we kicked off the start of a new unit by building a Driving Question Board to keep a record of what we are wondering. Now we will work together to make progress on those questions over the next several weeks. At the beginning of the day, or of a new lesson, we will use navigation to help us make connections between what we figured out the last time and what we want to do next.*

ADDITIONAL GUIDANCE The Navigation Routine is used throughout OpenSciEd units. It takes a slightly different form every time it is used. Sometimes it resembles a traditional “bellringer” or “exit ticket” task or discussion question. However, it reaches beyond these traditional classroom activities by not only asking students to recall what they learned (or as OpenSciEd units typically say, “figured out”), but also by pushing students to consider what new questions we have and how to figure out answers to those questions.

Start by recapping the first two bullets of questions on the slide to remind students why we wanted to capture images of electricity infrastructure in our community. Students will bring in home artifacts such as photos, drawings, or descriptions.

Suggested prompt	Sample student response
<i>What kinds of things did you take photos of that we can use to look for patterns?</i>	Wires, outlets, power lines, electrical boxes.
<i>What did we think taking photos of those things might help us figure out?</i>	They all relate to the electric grid, and we want to figure out how the grid works. We had a question about what structures in the system enable energy transfer from one source to multiple devices, buildings, and neighborhoods and we thought this could help answer that. It could help us spot similarities and differences in those structures.

Share patterns noticed across structures. Start with structures found outside of buildings, and then transition to structures found inside of buildings. Take less than a minute for each. End with focusing on the structure of the outlets. You can use the prompts below to guide this discussion.

Suggested prompt	Sample student response
<i>What are some things you noticed across the photos you took of structures that you found outside of buildings?</i>	(Accept all responses.)
<i>What are some things you noticed across the photos of structures you found inside of buildings?</i>	(Accept all responses.)

Suggested prompt	Sample student response
Let's look around the classroom. What kind of electricity infrastructure do you see?	There are outlets, wires, power strips, and switches.
A lot of us noticed outlets of various kinds. What kinds of patterns did you notice across the outlets that we find in this room and in our homes and other buildings?	They have three holes in them. They have two holes that are rectangular and one that is round, and there are usually two or four sets of these together.

Identify outlets as a common structure for further investigation. Say, *Since these three-hole outlet structures seem to be everywhere, they must be an important part of how energy is transferred to all the electricity-powered objects that need it inside a building. So, let's start there, as it might help us work backward in the larger-scale system to figure out how all these devices, buildings, and neighborhoods get the electrical energy they need. Let's get ready to dissect some of these smaller structures and figure out how they function.*

2 · IDENTIFY IMPORTANT SAFETY PRECAUTIONS

4 min

MATERIALS: Safety glasses with side shields or safety goggles, Safety poster

Identify important safety precautions. Show slide B. Remind students that electricity can be dangerous. Emphasize the importance of considering safety protocols and the impacts of our decisions in science and engineering, whether in the science classroom or in a professional setting. Pass out safety goggles for students to wear when working with circuits and show them how to use the safely.

Give students 30 seconds to read the question on the slide, and then discuss it as a class.

Suggested prompt	Sample student response
Tinkering with a power strip would be dangerous if it was hooked up to a wall socket. Why?	Electricity from the wall can electrocute you. You can get badly hurt or die from it.

Reveal or point to the Safety poster that you prepared before class. Say, *Individually and as a class, we have an ethical responsibility to consider the possible personal, societal, and environmental impacts of any scientific investigation we plan * or engineering solution we design. **

Identify steps you have taken to be consistent with the safety statement. Remind students that you are also committed to this principle. Say, *I have cut off the end of the cord so no one runs the risk of plugging a dissected power strip into the wall. And I have identified a safe source of electricity we can connect it to instead. That source will be a 1.5V battery, which cannot transfer enough energy into our bodies for us to even feel a shock.*

SAFETY PRECAUTIONS



Do not reuse these power strips for anything other than the battery-powered investigations in this lesson. Ensure that the plug is **completely removed** and dissected, or disposed of. Never plug the dissected or reassembled power strip, or the removed plug, into a wall socket or connect the wires to a high-voltage battery or other power source. It will be a serious shock or electrical fire hazard.

* SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Taking time to consider safety in the larger context of *designing solutions* can help position students as active caretakers of each other and the environment.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

An important element of planning and conducting an investigation or testing of a design solution at the high school level is to do so safely and in an ethical manner, including considerations of the personal, societal, and environmental impacts. Establishing this as an explicit principle and referring to it often will help students start to use it as a default lens to evaluate what they or others propose to do before doing it, such as when they outline or critique the protocols or proposed/alternate procedures for an investigation.

3 · DISSECT A POWER STRIP

8 min

MATERIALS: Dissection (Investigation A), *Power Strip Model*

Cue students to consider equitable participation. Distribute *Power Strip Model* to each student. Divide students into groups of 3. Show **slide C**. Read aloud, *What can you do to make sure everyone gets a chance to contribute their ideas?* Give students just a moment to think individually about this question.



Dissect the power strip. Distribute a set of Dissection (Investigation A) supplies to each group, and show **slide D**. Students should use their Phillips screwdriver to open up the power strip. They can carefully remove the metal strips, but they should not permanently disconnect anything. Remind students that they will need to reassemble the power strip at the end of the period for reuse by the next class.

While students work, direct their attention to *Power Strip Model*. Tell them to focus only on Part A for now. If they can't come up with anything yet, that's OK--they may have more ideas when we connect the power strip to an energy source.

ASSESSMENT OPPORTUNITY

Identifying at least two **parts and/or interactions they observe inside** (CCC: 4.1) the powerstrip. These might include:

- Three metal strips connected to wires of different colors
- Colored Insulation around wires / space between metal strips
- The alignment of certain holes in each socket to one of these metal strips.
- The switch connected to one color wire at two points

What to do: Support small-group sensemaking by asking probing questions about what students notice about the metal parts in the system and where they are connected. Encourage them to start recording this in Part A of *Power Strip Model* as they identify these parts.

Building toward: 2.A.1 Collect data from a **designed system** (a power strip) and a network of **interconnected subsystems** (multiple powerstrips) on the **interactions needed for** and **failure points in the transfer of electrical energy**. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1)

Foreshadow the next investigation. Tell students that after you distribute supplies for the next investigation, you will hook up a single light bulb to a single battery with no power strip, to establish a control condition for the whole class.

4 · POWER THE CIRCUIT

10 min

MATERIALS: Powered Circuit (Investigation B)

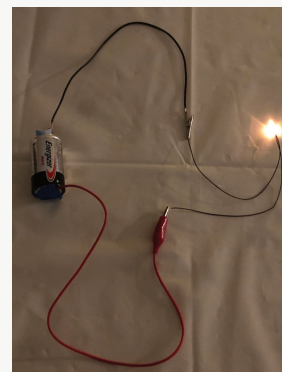
Review the parts of this investigation. Show slide E. Tell students that after you distribute supplies, their goal will be to light up multiple light bulbs as brightly as the one at the front of the room, but using the power strip as an intermediate energy transfer mechanism. Show them the control condition now at the front of the room. *

Distribute a set of Powered Circuit (Investigation B) supplies to each group. Each group will also need their dissected power strip from Investigation A.

Carry out the investigation. Have groups start the investigation. Remind students to complete Part A on the handout as they do so.



Monitor groups. Move around the classroom and listen to students' insights from the remaining parts of the investigation.



* ATTENDING TO EQUITY

Supporting emergent multilinguals: You might need to spend a moment reminding students what it means to provide a *control* condition, particularly if your students are multilingual. A control provides a standard against which other conditions can be compared in a scientific investigation, but it means something very different in everyday language. Highlighting how words can have different meanings in different contexts (i.e., in science versus everyday use) gives emergent multilingual students the opportunity and space to discuss any preconceptions about the meaning of the word(s), and to draw upon their personal experiences.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment.

- Connecting alligator clips to different metal parts to determine which connections are needed for energy transfer from the battery to each light bulb and recording the results. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1;)
- Testing the effect of the switch and noticing it turns on or off all devices together. When the wire connected to the switch isn't used for any devices, the switch does nothing. (SEP: 3.6; CCC: 4.1)
- Connecting additional devices in certain configurations (e.g., parallel versus series) either does or does not appear to affect the amount of energy transferred (brightness) to each light bulb. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1)

What to do: Support small-group sensemaking by asking how many connections needed to be made back to the battery, and what other connections in the system needed to be made, in order to provide energy to the electronic devices. Some groups may discover a way to provide energy to the light bulbs by hooking them up in a series. As the focus of this investigation is not on distinguishing parallel versus series circuits, this is fine. If time permits, however, you could challenge these groups to consider whether the light bulbs are as bright as the one in the control condition, which may lead them to notice it is not and will motivate exploring other possible arrangements of the parts in the system.

Building toward: 2.A.2 Collect data from a designed system (a power strip) and a network of interconnected subsystems (multiple powerstrips) on the interactions needed for and failure points in the transfer of electrical energy. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1)

ALTERNATE ACTIVITY

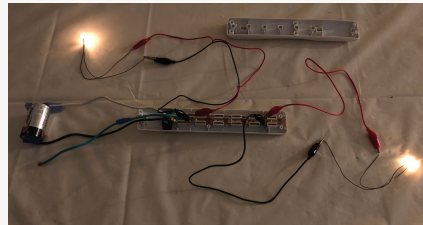
If you have access to small 1.5V DC motors you can include these in students' lab supply bins so they can hook up these type of devices to the power strips as well

SAFETY PRECAUTIONS

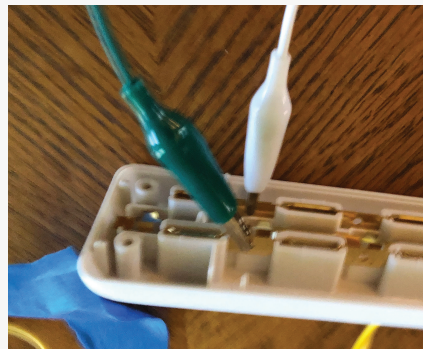


If the battery heats up quickly, this is a dangerous condition in the system called a short circuit. Remind groups to carefully check their battery periodically (e.g., every minute) to make sure this isn't happening. When a group detects this condition, have them detach the wires from the battery. Look for any locations where wires/connections that can be traced back to the two ends of the battery are accidentally touching each other without any electronic device (a light bulb or motor) between them and correct this before testing it again.

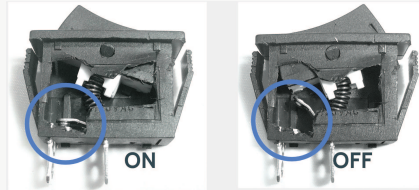
An example of part 2 of Investigation B is shown to the right, with only two light bulbs attached to the power strip: one attached to the back end and another to the front end. Either position is OK. Again, this image is for teacher reference only. Allow students space to tinker and make productive mistakes without providing explicit guidance about what the end product will look like.



Here is what the system may look like when students are attaching the alligator clips to the back side of the power strip.



Here is what the dissected power strip switch looks like. DO NOT encourage students to dissect the switch in the power strip, or the switch will likely no longer be functional. For any groups that have ideas or questions about the internal structure of the switch, emphasize that this line of thinking or questioning seems very productive, and that we should take some time in a few minutes to dig into this question as a class.



Reserve 2 minutes to lead this next discussion to motivate looking into the switch further before moving on to the next activity.

Explore how the switch works. Say, *How is this switch constructed to allow the power strip to turn all the devices on or off together? If we can't take apart the switch in our own power strip, how can you change the system to do the same task? Take a moment to find a connection that will change the circuit in the same way that the switch does.* Give groups 30 seconds to try to find a way to change the connection(s) in their dissected power strip system to produce the same outcome as turning the switch on or off. Say, *Let's now compare the structural change you made to the system with an image showing us what structures are inside these types of switches.*

If using Google Slides, display **slide F**. Explain that the switch in this animation is like the one in the power strip, but has the side cut open to show its internal structure. Show the animated gif, and give students 1 minute to talk about the question on the slide and the related images with an elbow partner.

If using Powerpoint or a PDF copy of slides, display **slide G**. Explain that the images show a switch like the one in the power strip, but has the side cut open to show its internal structure. Give students 1 minute to talk about the question on the slide and the related images with an elbow partner.

5 · DEVELOP A MODEL FOR EXPLAINING HOW THE POWER STRIP SYSTEM WORKS

12 min

MATERIALS: *Power Strip Model*, whiteboard or piece of chart paper (optional)



Develop a model for explaining how the power strip works. * Show slide H. Emphasize that you are going to ask students to use their observations to develop a model for explaining how the structure of the objects they just observed enables the system to function.

List key structures. Before students make their diagrams, say, *Which groups made progress on Part A? Which key structures in the system enable the power strip to transfer energy from one source to multiple devices?* You may also choose to write the list on a whiteboard or chart paper at the front of the room, explaining that these parts may or may not be needed to explain how the power strip functions, and the list may or may not be complete, but that you wanted to record examples from all the investigation groups so everyone can consider whether they are necessary parts. It doesn't matter whether this list is complete. Listen for students to suggest key structures such as the three strips of metal, the wires and the rubber coating, the switch, the battery, and the bulbs.

Complete Part B. Remind students that whenever we develop a model in science, it is made *for explaining something*, and it isn't just a model of *what we see*. In other words, it seeks to help explain how and/or why something happens. A diagram doesn't have to look much like a power strip to *explain how the structure of the power strip makes it possible to transfer energy from one source to multiple devices*. Remind students of the initial consensus model of the larger-scale system the class created in Lesson 1 as an example of abstract representation.

Instruct students to draw their model in Part B of the handout. Emphasize that you will collect this in a few minutes, so you can give feedback to help them improve their fluency in modeling. Look for students' diagrams to include the following details about the structure and connections inside the power strip:

- **Metal strips and wire structure(s) and interactions (connections):** Three continuous metal strips, connected to three different colored wires, are all inside the larger white cord.
- **Energy source to power strip connections:** Two separate metal paths from different ends of the battery need to be connected to different wires inside the power strip's cord.
- **Power strip connections to electricity-powered object connections:** Two separate metal paths from two different metal strips in the power strip need to be connected to each electricity-powered device in order to power them.
- **Switch connections:** One color wire is connected to one prong of the switch, and the same color wire leads away from the other prong. Turning the switch off/on does the same thing as completing/breaking the connection to this colored wire.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: *Students' models of the power strip system should be a circuit diagram, showing which parts in the system need to be connected in order for the system to work as designed for energy to transfer from the source to multiple devices.* Models should be clear enough to serve as a tool for identifying whether those connections exist. (SEP: 2.3; DCI: PS3.B.2; CCC 6.1)

What to do: If students do not label the parts of the system, leave a sticky note on their model before returning these to students in the next period, prompting: *What are the key structures in the system? Can you label them?* If students' models do not show connections clearly enough to determine whether devices would receive energy, leave a sticky note prompting: *What structures are connected to what? How does your model help us see which devices receive energy?*

Building toward: 2.B.1 *Develop and revise a model of connections of components involved in electricity infrastructure to explain how specific structures function to change the way electrical energy transfers within and between systems at different scales.* (SEP: 2.3; DCI: PS3.B.2; CCC: 4.3, 6.1)

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Students may think of a "model of the power strip system" as only a diagram of the power strip and may focus on capturing as much visual detail as possible. Help them realize that in science, modeling does not always mean drawing a representative picture. Instead, we're trying to capture the key parts and interactions that help explain something about a phenomenon. In this case, its purpose is to explain how the structure of the power strip makes it possible to transfer energy from one source to multiple devices.

Note that this model does not focus explicitly on mechanisms for energy transfer or matter transfer--these will emerge through other modeling later in the unit.

6 · CLEAN UP AND ASSIGN HOME LEARNING

5 min

MATERIALS: science notebook, *Electricity Related Parts*, *Power Strip Model*, Investigation A supplies, Investigation B supplies

Reassemble and sort the lab supplies for the next class. Show slide I. Tell student groups to follow the instructions on the slide for reassembling their power strips and sorting the supplies. Note: With your last class of the day, skip the reassembly step. Keeping the power strip disassembled and the light bulbs attached to it will make it easier for you to prepare the materials for Investigation C.

As students clean up, disassemble the control condition. Put these materials aside to reassemble for the next class you teach.

Assign the exit ticket. Show slide J. Have students write their answer to the question on the slide on the back of *Power Strip Model* as an exit ticket.



Motivate home learning. Show slide K. Read the text at the top of the slide aloud to remind students that the structure of the power strip is similar to the way in which multiple outlets in a building can be hooked together to ensure that they can all get electricity from just three wires coming into the building. Distribute *Electricity Related Parts* to each student. Read the text at the bottom of the slide aloud to encourage students to think of the power strip as a physical model of other connections. *

Collect *Power Strip Model* with the models and exit ticket responses before students leave.

* ATTENDING TO EQUITY

All students will benefit from a reminder to annotate *Electricity Related Parts* as they read at home. The CATCH method of annotating is a good choice if students are familiar with it. A description of the CATCH method can be found in the OpenSciEd Teacher Handbook: High School Science. Additionally, students who do not read at or above grade level will benefit from a reminder that the Google version of *Electricity Related Parts* is accessible to screen reading technology and online translator services.

End of day 1

7 · NAVIGATE AND SHARE NEW IDEAS

5 min

MATERIALS: science notebook, *Electricity Related Parts*

Share new ideas from the home learning. Show slide L and pose its questions:

- What questions did the investigations from last class raise for you that the reading helped answer?
- What new ideas did the reading give you about how electrical energy systems function in our own neighborhoods, or about what might have happened in Texas?

Ask students to share some of the things they identified in the reading that are related to either of these questions. Sample student responses include:

- Transferring electrical energy to any electronic device in a building requires at least two separate, continuous paths of charge-conducting metal wire (a complete circuit).
- There are at least two wires that come into a building to provide these paths.
- There is often a third wire that all the electrical sockets' center holes are connected to, which comes out of the building and goes into the ground as a safety feature for surges in energy.
- There are other safety features, such as circuit breakers that open (break) the circuit in conditions where there is too much electrical energy transferring through the system.
- Maybe something caused a lot of short circuits or broken circuits in Texas.

8 · DEVELOP A CLASS CONSENSUS MODEL FOR HOW THE POWER STRIP SYSTEM WORKS

12 min

MATERIALS: *Power Strip Model*, colored markers (blue, red, and green), tape, blank paper (half sheet), Power Strip and Battery System Model poster, piece of blue yarn, piece of red yarn, Powered Object cards, Switch Description card

Motivate developing a model of electrical wiring in buildings from what we know about the power strip. Say, *In the last class, we started considering how the structures inside the power strip transfer electrical energy to multiple outlets. We saw that they are similar to the structures in a building that transfer energy to multiple outlets from just three wires coming into the building. You've identified some of those structures in the reading. Distribute the models on Power Strip Model that you collected at the end of the last class, with feedback.*

Introduce the goal of the Building Understandings Discussion. * Say, *Let's develop a map of some of those basic structures in both systems--a power strip and a building--so we can better understand how these systems function.*

Ask students for examples of a set of nonverbal signals (e.g., ASL signs) to adopt as a class for signaling agreement, disagreement, and wondering/questioning, as a way to ensure equitable participation in ideas that others are proposing.

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Be explicit with students about your role in this discussion, which is to press them for evidence when they bring up ideas for how the types of interactions compare. Tell them, *My role in this discussion is to press for evidence, regardless of whether the ideas are right or wrong. So you might hear me ask, "Where did you see that?" It is my job to push us as a class to articulate the evidence we have to support our ideas.*

KEY IDEAS

Purpose of this discussion: To come to consensus about what the key parts and connections in the power strip are. These are the same parts and connections you looked for in the previous Assessment Guidance box, when you gave feedback to students on their models.

Listen for these ideas:

- **Metal strips and wire structure(s) and interactions (connections):** There are three continuous metal strips, connected to three different colored wires, which are all inside the larger white cord.
- **Switch connections:** One color wire is connected to one prong of the switch, and the same color wire leads away from the other prong. Turning the switch on/off does the same thing as completing/breaking the connection to this colored wire.
- **Energy source to power strip connections:** Two separate metal paths from different ends of the battery need to be connected to different wires inside the power strip's cord.
- **Power strip connections to electricity-powered object connections:** Two separate metal paths from different metal strips in the power strip need to be connected to each electricity-powered object in order to power them.

Establish consensus around key parts. Show slide M. Use the prompts below to facilitate this part of the discussion.

Suggested prompt	Sample student response
What were some of the parts inside the power strip that you included in your models of that system?	Three metal strips. Wires connecting to each strip. A switch. The cord holding the three wires together.
What was the energy source for the power strip when we used it to light up multiple light bulbs?	The battery.

Suggested prompt

Which wires did you connect to the energy source?

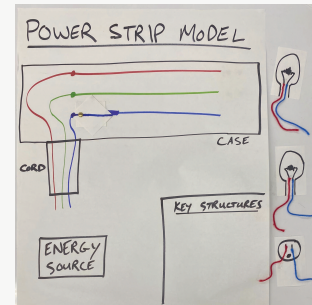
Sample student response

The black wire and the white wire.

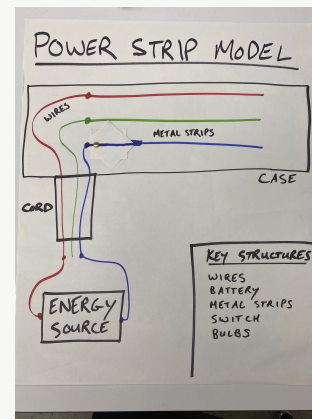
Any two wires would work, but the switch only worked if we used the black wire.

Assemble the Power Strip and Battery System Model poster as a class. Follow the steps below to assemble the poster.

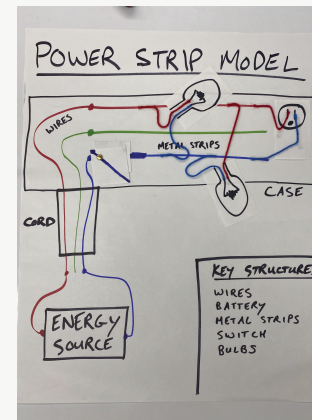
Hang (or uncover) the Power Strip and Battery System Model poster, with the bulbs, yarn, and other components nearby. Say, I've started representing some of these structures here, too. I've used three colors to represent the different strips of metal and the wires that connect to them all the way back to the prongs on the plug. To get us started, what are some key structures that we definitely need to include in our model? Write down key structures on blank paper (half sheet) taped in the "Key Structures" box as students mention them: wires, battery, metal strips, switch, bulbs.



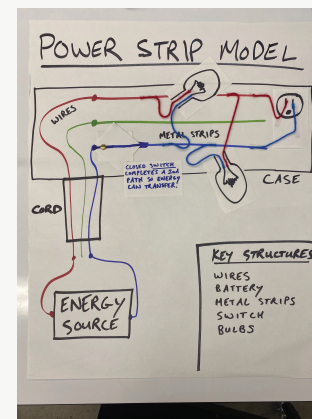
Ask students, What parts of this system did you connect to the battery, and what part of the battery did you connect them to? As students mention them, tape one piece of blue and red yarn between each end of the battery and the blue and red wires of the power strip.



Ask students, Which part of the system did you connect to each of the two wires on the light bulbs to get them to light up? Hold up one Powered Object card. Say, This represents any one of the devices we used yesterday that needs electrical energy transferred to it in order to work (light up). As students mention them, tape one piece of blue yarn from the card to the blue wire of the power strip, and tape one piece of red yarn from the card to the red wire of the power strip. Repeat this for the two other Powered Object cards.



Demonstrate changing the orientation of the on/off switch in the model. Twist it back and forth, then leave the switch in an off/open position. Ask students, How many continuous metal paths from the energy source to the electricity-powered object are there when the switch is in the open position? What about the closed position? Twist the switch to an on/closed position. After students respond, emphasize that when there are two paths to or from the two ends of the energy source, the devices get electrical energy transferred to them. Explain that this condition is called a closed circuit, and this is because you can trace a continuous circuit, or loop, between the energy source and the device it is transferring energy to. Trace this path for students along one circuit on the poster. Tape the prepared Switch Description card that says "closed switch provides a 2nd unbroken metal path so energy can transfer" near the switch on the poster.



9 · DEVELOP A MODEL FOR CIRCUITS IN A BUILDING

8 min

MATERIALS: Power Strip and Battery System Model poster



Introduce the goal of the next Building Understandings Discussion. * Say, *Let's develop a map of what some of those basic structures are in both systems--a power strip and a building--so we can better understand how these systems function.* Show **slide N**.

Say, *To ensure equitable participation from everyone, remember our nonverbal signs for agreeing or disagreeing with claims that others are making.* Encourage students to take out their copy of *Electricity Related Parts* as a reference. Use the prompts below to facilitate the discussion.

KEY IDEAS

Purpose of this discussion: To come to consensus about which parts and connections in the electrical system of a building (larger scale) are analogous to parts and connections in the power strip (smaller scale), based on what students uncovered in the reading.

Listen for these ideas:

- **Wire structure(s) and interactions (connections):** There are three different colored wires inside the larger white cords running through the walls. Insulation makes it hard for electrical connections to be made to these wires accidentally.
- **Switch connections:** There are on/off switches that do the same thing as completing/breaking the connection to one colored wire. A circuit breaker or fuse is just an automatic switch that turns off when things aren't safe.
- **Energy source to wire connections:** Two separate metal paths from different ends of the power source are connected to different wires coming into the building.
- **Ground wire:** One separate metal path in the building leads into the ground. It is not usually insulated. If there is extra electrical energy in other parts of the system, the ground wire gives it a safe place to go.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Listen for the key ideas outlined in the box above. The power strip serves as a **physical model of the building at a larger scale**. Many structures are present in both, and **students should highlight similarities in the models of those two systems**. (SEP: 2.3 CCC: 4.1, 6.1)

- Students' connections may include: circuit breakers, switches, insulation, and ground wire.

What to do:

- If students do not connect structures from the reading to the power strip, say, *How does that structure relate to our model of the power strip?*
- If students do not explicitly emphasize structure and function, ask for more with a targeted question such as, *How does the structure of the wires in the building function to help us get electricity safely?*
- If students do not recall the function of a particular structure in this system (e.g., circuit breaker, insulated wires, ground wire), prompt them to take a minute to look back at *Electricity Related Parts* for any related information and underline it before sharing out.

Building toward: 2.B.2 Develop, revise, and use a model to identify **analogous structures** that affect the **electrical energy transfers across and between different (sub)systems at different scales** (powerstrip, building, community). (SEP: 2.3; DCI: PS3.B.2; CCC: 4.1, 6.1)

Suggested prompt	Sample student response
<i>How does the scale of a building compare to the scale of the power strip?</i>	The building is much bigger. The wires in a building have to be longer to make those connections.
<i>Even though the systems work at much different scales, we can still look for similarities. How is the structure of the power strip similar to structures in a building that transfer electrical energy?</i>	There are three wires, and there is a switch, and you can hook devices up to the wires.
<i>How many wires go to each socket in a building?</i>	Three.
<i>What sort of structures are in a building that break the energy transfer in a circuit on purpose?</i>	Wall switches, GFCIs, circuit breakers.
<i>What did you notice about the wires that run through the walls of buildings that's similar to the structure of the power strip cable?</i>	They each have three wires in one single cable. They're all together in one wrapping.
Introduce the model's representation of wires in a building. Show slide O. Say, <i>In the reading, you saw images showing that the wires connecting a building's electrical outlets to its electrical panel typically look like a single cable, as shown here. But as you said, if we peel back the surrounding sheath on the cable, we can see separate, insulated wires within it. Though the wires in the photo are black, copper, and white, the model on the slide uses blue, green, and red for easier identification on the white background.</i> Compare how outlet wire connections are represented. Show slide P. Say, <i>You also saw an image showing that the outlets are connected to three wires as well. These three wires connect to the three wires in the cables in the walls, like the outlet shown on this slide. How does this compare to how we connected the electricity-powered devices in our model of the power strip?</i> Listen for students to say that we connected only two wires to the metal strips, and that we didn't connect anything to the green wire. Describe why some devices have two prongs on the cord. Show slide Q. Say, <i>Some electricity-powered objects that don't use a lot of energy have plugs with only two prongs on them. Their prongs only touch the blue and red wires shown on the diagram.</i> Introduce the connection to the energy source. Show slide R. Explain that at least two wires need to be connected to an energy source that can transfer electrical energy through the circuit, and that such energy sources are typically far away from the buildings to which they provide energy. Emphasize that the energy source isn't shown in the model, and that the dotted lines represent that these wires extend for many miles back to an energy source (or sources).	

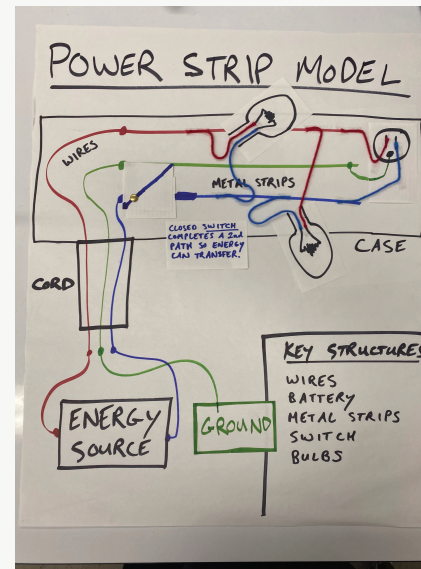
Problemalyze the function of the green wire. Say, *OK, let's talk a bit about the function of this third wire, shown in green, that is connected to the middle hole in the outlets.* Show **slide S**. Give students 1 minute to discuss the question on the slide with an elbow partner.

Ask students for their thoughts on the role of the ground wire, then ask why we didn't include a ground connection in our power strip model. Ask, *Should we add it? Do those connections matter for how the power strip is constructed?* If students think it's important to add a ground connection, tape the prepared Ground card to the bottom of the Power Strip and Battery System Model poster, then use a green marker or yarn to connect it to the green wire.

Show **slide T**. Say, *This model shows only a single circuit breaker. In this case, that circuit breaker switch is right near where the wires come into the building, which is where that electrical panel is typically located.*

Poll students on their use of a circuit breaker. Say, *How many of you have had someone in your building reset the surge protector or circuit breaker after it automatically shut off and broke the circuit?*

Motivate developing a neighborhood-based model. Say, *Now let's think again about scale to connect back to our initial consensus model from Lesson 1. In our discussion just now, we mapped connections between structures in the power strip and structures in a building. Let's see how we can use these patterns to scale up a step further, to model how multiple buildings in a neighborhood are connected to the same energy source. If each group wires their own building, we can then connect these buildings into a neighborhood.*



10 · USE THE POWER STRIP MODELS TO INVESTIGATE ELECTRICAL DISTRIBUTION IN A CITY

7 min

MATERIALS: Electrical Distribution in a City (Investigation C)

Assemble the model buildings and test their lights. Distribute Electrical Distribution in a City (Investigation C) supplies to each group. Display **slide U**. Have students confirm that only 2 light bulbs are hooked up to their powerstrip and test that it runs on when they hook it up to a battery. Debug the connections, if necessary.

ADDITIONAL GUIDANCE

We are limiting the total number of these lights you hook up to a 1.5V battery to 2 per strip, which will be 14 total. Because each bulb will draw 100mA, this many bulbs will draw just over 1.4 A. Connecting additional lights will start to draw more current and reduce its life.

Have each group label a paper tent with the name of a building that people in a community might need; for example, a grocery store or a gas station. They can decorate the paper tent how they'd like if they have time.

ALTERNATE ACTIVITY

If there is time, this could be an opportunity for your students to build and decorate their own cardboard boxes, bringing some of their creative-crafting skills into the science classroom. The default suggestion is to prepare boxes ahead of time using *Preparing Cardboard Buildings* and distribute them to the student groups.

If you do this, have students choose what building their boxes represent (a hospital, a store, a school, a detached house, an apartment complex) and label them. Students can add paper tents on top of the buildings they create or decorate the cardboard directly.

Set up the class energy source and substation. While students work on their buildings, set up the demonstration area in another part of the room. Plan for this to take up a square space 4-6 feet on each side. If possible, route extra alligator clips or wires in pairs a few feet away from the battery in multiple directions, to allow space for each group to connect their building easily. Spreading out will help clarify the role of individual buildings and other system components (substation, wires, switches), and facilitate student-to-student talk in the class discussion about parallels to structures in students' own neighborhoods.

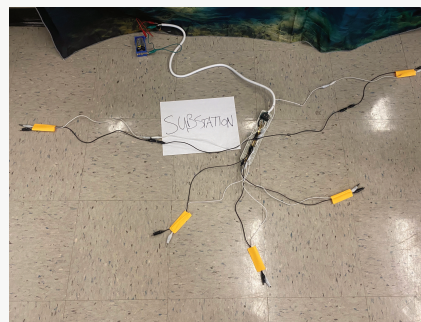
Label the energy source and substation. Make sure the power strip switch is turned off.

Combine the buildings into a model neighborhood. When students are ready, have them bring their buildings and give you their batteries as they gather around the demonstration area. Instruct them to connect their buildings to the substation with one of the pairs of wires provided.

Display **slide V**. Have students turn and talk to discuss how this model shows how multiple buildings in a neighborhood could get electricity from one energy source.

Explain that a typical substation has a similar function as the power strip in this system, serving as a common junction point for distributing energy to multiple customers. A typical residential substation serves this function for approximately 1,500 customers. Remind students to consider scale--when you plug in an electricity-powered device, you are creating a giant circuit from that device near you to a power source that may be very far away.

A single 1.5V D battery should be enough to light up seven "buildings" at two bulbs per "building," but the lights may dim. If the battery is old, the lights will likely dim too much, which may be misleading for students. One possible solution to this problem is to prepare a "stronger" 1.5V battery--this means attached multiple D batteries in parallel--with positives connected to each other. If you happen to have apparatus for this, such as the holders on the left in the image shown, use them. If you don't, use paper clips and tape as shown to create your own parallel battery pack.



ADDITIONAL GUIDANCE

We are simplifying how we are thinking about circuits at this point. The unit does not investigate the role of transformers. Though transformers could be thought of as physical gaps between two circuits, one could also think of them as power sources. As we will discover in Lessons 5 and 6, all energy transfer via circuits is due to the propagation of electric and magnetic fields through empty space between matter. From that perspective, the transformers in an electrical grid are just one more location where there is some empty space in the system.

Turn on the switch of the substation power strip. Have the class make note of which buildings' lights go on. Point out any building where the lights didn't go on, and explain that this may be due to a short circuit or a broken circuit in the system.

11 · USE THE MODEL CITY TO INVESTIGATE POWER OUTAGES FROM SHORT CIRCUITS AND BROKEN CIRCUITS

6 min

MATERIALS: science notebook

Simulate the effects of broken circuits and short circuits. Show slide W. Say, *We learned that there are circuit breakers built into buildings, and even into many power strips, that will automatically break the circuit if a short circuit is detected. Similar safety features are built into points in the electrical system, like a substation, which is a single point in the electrical wire network that connects thousands of buildings. Let's see what happens to electrical energy in the system when there is a broken circuit.*

Break one of the lines before the substation to show that all the connected buildings lose power. Identify this as a broken circuit. Then reattach that wire and break a line to one of the buildings to show that only that building loses power. Identify this as a broken circuit in a different part of the system.

Lay a large paper clip across two lines on the wire connecting the substation to a building. This connection needs to be strong, to show that all buildings lose power in this condition. If the lights only dim slightly, the connection isn't strong enough. You may instead try attaching the alligator clips to the metal, while maintaining the original connection.

Identify this as a short circuit. Say, *If a short circuit is created, most of the energy will transfer down that path rather than through the other circuits. Notice that the entire neighborhood loses power. However, if we switch off the part of the circuit that contains the short circuit, the rest of the system gets power back.*



Consider the role of circuit breakers during accidents. Show slide X. Say, *Now that we've seen the effect of a short circuit, consider what might happen during an accident. Imagine a tree has fallen on a power line and created a short circuit and an electrical fire. How can a circuit breaker, either in a building or at a substation, help limit the scale of a power outage due to that short circuit?*

If students' answers aren't clear, demonstrate the short circuit again. Say, *If the short circuit is in this building, then the entire neighborhood goes dark. But watch what happens to the neighborhood when we turn off the switch to that building. This is one role that a circuit breaker plays in our buildings and substations.*

Add new words to our Personal Glossaries, and add to our Progress Trackers. Present slide Y. Give students a chance to record their thinking in their *Progress Trackers*. Also take a moment to give students a chance to add to their students' Personal Glossaries. Some words the class might decide to add include *switch, circuit, ground, and substation*. You might also consider adding the phrases *incandescent, insulator, short circuit* and *broken circuit*.

Name the model neighborhood. Ask students what we should call the model neighborhood we built. In this *Teacher Guide*, we sometimes refer to it as "Electric City."

ALTERNATE ACTIVITY

Extension opportunity: This step in the lesson sequence is another opportunity for creative input from students outside of what is described here. They may want to make a sign, or spend more time decorating and labeling their buildings or the city itself. If students feel invested in their city, this setup can be used again in Lesson 3 and Lesson 7.

12 · ADD TO OUR COMMUNITY AGREEMENTS

3 min

MATERIALS: science notebook, *Community Agreements*, Community Agreements poster from Lesson 1

Reflect on our Community Agreements. Ask students to look back at our Community Agreements. Then ask, *What would it look like in a group if participation were equitable and respectful?* Look for ideas about everyone getting to talk, or everyone's ideas being heard. Students might also mention that some people prefer to express themselves in other ways, including the nonverbal ones you introduced earlier.

Add to our Community Agreements, with a focus on the “Equitable” and “Respectful” categories. Present slide Z. Ask, *What can we add to our Community Agreements to support equitable participation?* Have students turn and talk to develop some ideas for how we could make participation more equitable, and then share out after a minute. Add their ideas to that category on the Community Agreements poster from Lesson 1, and ask students to keep track of new agreements on *Community Agreements*, added to their notebooks in Lesson 1.

Look for at least 2-3 ideas. Consider getting the conversation started by suggesting an agreement such as: “We recognize and value that people think, share, and represent their ideas in different ways.”

ADDITIONAL GUIDANCE

If students suggest ideas for the teacher only, such as “You should call on everyone,” explain that you definitely want to make choices that will encourage equitable participation, and that you appreciate feedback, but that this time is for agreeing on things we can *all* do to support the culture we want to see.

ALTERNATE ACTIVITY

As in Lesson 1, if students have a lot of ideas, you may want to start a new piece of chart paper to keep track of them. In later lessons, you will have the opportunity to distill these ideas, and you can add them to the Community Agreements poster then.

13 · NAVIGATE

4 min

MATERIALS: sticky notes, markers

Navigate with a Turn and Talk. Show slide AA. Say, *In this lesson, we figured out how a circuit is needed to transfer energy from a source to electricity-powered devices.* Have students talk with a partner for 1-2 minutes about the question below and then discuss it as a class.

Suggested prompt

What new ideas or new questions does this raise for you about our Texas case study?

Sample student response

Did the weather cause broken circuits?
Did ice and snow break the power lines?
Did the wind blow down wires?
How many power lines fell down during the storm in Texas?

Emphasize that we should plan to investigate these questions next time. Remind students, if time permits, that they can add these questions to the Driving Question Board before class is over. Distribute sticky notes and markers for this.

LESSON 3: Could the blackouts in Texas have been caused by a broken or short-circuited circuit?

PREVIOUS LESSON We compared photos and drawings of structures that provide electricity. We dissected a power strip and connected it to a battery to power multiple devices. We developed a model of how structures of the power strip system enable it to transfer energy from one source to multiple devices. We test the effects of short circuits and broken circuits.

THIS LESSON

INVESTIGATION

3 days



FEMA, M. Raphael

We read about an energy crisis that began in Ohio, and a strategy engineers have used to prevent short and broken circuits in power lines. We use a new tool, the Engineering Design Tracker, to keep track of our ideas to inform possible design solutions, including criteria and constraints. We develop an energy transfer model to explore various scenarios that could result in little or no electrical energy transferred to communities. We analyze data about electricity supply and demand, and we find out that change in supply must match changes in demand to avoid a crisis. We brainstorm ideas of what could have caused the drop in supply we observed in Texas.

NEXT LESSON We will use informational cards and several data representations from the 2021 Texas crisis to seek additional information about specific sources of energy to help us figure out which source might be responsible for the drop in supply. We will use a new tool called Decisions Matrix to keep track of how well each source meets criteria we think are important.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

3.A Develop and use a model based on evidence from our investigation in Lesson 2 to illustrate the energy flow between components of the electric grid system and energy loss from the system as a possible cause of the crisis in Texas. (SEP: 2.3; DCI: PS3.B.2, PS3.D.1; CCC: 4.3)

3.B Evaluate the impact of empirical data about energy supply and demand from Texas in February 2020 and 2021 to identify patterns, and evaluate how scientific knowledge and constraints impact possible solutions. (SEP: 4.5, 6.5; DCI: PS3.B.4; CCC 1.5, Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)

WHAT STUDENTS WILL FIGURE OUT

- Engineering constraints can affect the implementation of a possible solution.
- The production of electrical energy must match the demand for electrical energy.
- The cold temperatures during the Texas blackout probably caused a spike in energy demand, which was accompanied by a drop in the supply of electrical energy.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Briefly discuss what was figured out in the last lesson and what happens to energy transfer when there is a short circuit in the electric grid.	A	
2	15 min		READ ABOUT A POWER OUTAGE EVENT Distribute the reading to complete and annotate in class.	B	<i>Undergrounding Power Lines</i>
3	10 min		INTRODUCE THE ENGINEERING DESIGN TRACKER Introduce the <i>Engineering Design Tracker</i> as a tool to keep track of ideas to help inform community solutions. Fill in Parts 1-2, introduce the concept of constraints, and fill in Part 3.	C	<i>Engineering Design Tracker</i>
4	12 min		DEVELOP A MODEL TO REPRESENT ENERGY TRANSFER IN THE SYSTEM Transition to a different energy transfer model, and discuss using simple conventions to represent the parts of the electric grid and energy transfer between them.	D-F	
5	5 min		NAVIGATE: EXIT TICKET Use an exit ticket to motivate looking at alternative scenarios that could result in little or no energy being transferred in the grid.	G	piece of paper for exit ticket
End of day 1					
6	5 min		NAVIGATE Motivate where to go next by asking students what data they would like to see from Texas that could help us understand how energy transfers through the various parts of the system.	H	
7	25 min		MODEL ENERGY TRANSFER IN VARIOUS SCENARIOS Introduce and model scenarios on the handout in pairs, and provide/incorporate peer feedback. Use the energy transfer representations to identify areas of uncertainty and motivate the need to quantify how much energy goes to the various parts of the system.	I-K	<i>Energy Transfer Scenarios</i> , blue pen
8	15 min		ANALYZE GRAPHS OF FORECASTED ELECTRICITY DEMAND Identify and interpret patterns in graphs of electricity demand forecast from Texas in February 2020 and February 2021.	L-N	<i>Electricity Demand Forecast</i>
End of day 2					
9	5 min		NAVIGATE Remind students about the graphs we analyzed last time, and dig deeper into what it means to forecast demand.	O	
10	10 min		ANALYZE GRAPHS OF ELECTRICITY PRODUCTION AND DEMAND Identify and interpret patterns in graphs of electricity production from Texas in February 2020 and February 2021. Compare these to graphs of electricity demand forecast and electricity use.	P-Q	<i>Electricity Production</i>
11	25 min		DISCUSS ABOUT ENERGY SUPPLY AND DEMAND IN A SCIENTISTS CIRCLE With two student volunteers leading the discussion and two using the discussion mapping tool, work as a class to come to agreement about two scenarios on the modeling handout.	R-T	<i>Energy Transfer Scenarios</i> , <i>Discussion Mapping Tool</i>

Part	Duration		Summary	Slide	Materials
12	5 min		NAVIGATE: EXIT TICKET Add new terms to students' Personal Glossaries. Brainstorm where to go next with an exit ticket.	U-W	blank sheet of paper, <i>Discussion Mapping Tool</i> <i>End of day 3</i>

Lesson 3 • Materials List

	per student	per group	per class
Lesson materials	• <i>Undergrounding Power Lines</i> • <i>Engineering Design Tracker</i> • science notebook • piece of paper for exit ticket • <i>Energy Transfer Scenarios</i> • <i>Electricity Demand Forecast</i> • blank sheet of paper	• blue pen • <i>Electricity Production</i> • <i>Energy Transfer Scenarios</i>	• <i>Discussion Mapping Tool</i>

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Access <https://www.eia.gov/electricity/gridmonitor/dashboard/custom/pending> to get familiarized with the U.S. Energy Information Administration website. When exploring electricity demand forecast with students, looking at the electricity demand in their own community might help them grasp this concept. Use <https://www.youtube.com/watch?v=ocu9UKskKaM> for guidance of how to find the electricity demand in a particular region.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS3.B: Conservation of Energy and Energy Transfer.** The availability of energy limits what can occur in any system. (HS-PS3-1)
- **ETS1.B: Developing Possible Solutions.** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)
- **PS3.D: Energy in Chemical Processes.** Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3) (HS-PS3-4)

This lesson introduces a new scaffold (the *Engineering Design Tracker*) and a new set of modeling conventions (the energy transfer model). The *Engineering Design Tracker* is a tool to keep track of how engineers use science ideas to design solutions. It also asks students to identify constraints that may prevent those solutions from being implemented. This tool will be used in subsequent lessons to help students connect their new understandings to answer the unit question: “How can we design more reliable systems to meet our communities’ energy needs?”

The energy transfer model differs substantially from other approaches to energy instruction in that it does not focus on identifying or labeling energy forms. Instead, this representation emphasizes the transfer of energy between various parts of the system and the interactions that cause this transfer. In this lesson, students will use this model to identify the need to quantify energy transfer throughout the system and to identify parts of the system that must be explored further.

Students will encounter or co-develop definitions for the following words in this lesson: *criteria, constraint, supply, demand*. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students will not discuss trade-offs until the second lesson set in this unit. At that point, they will learn about trade-offs between criteria and constraints, and consider how the values of interested parties can inform decision making when trade-offs are involved.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

3 min

MATERIALS: None

Orient the class to where we left off. Present **slide A**. The table below provides examples of how students might respond to each prompt on the slide.

Suggested prompt	Sample student response
<i>What did we see last class when there was a short circuit in our city?</i>	The short circuit caused the battery to get hot.
<i>What did we see when there was a broken circuit?</i>	The lights turned off when there was a broken circuit.
<i>How would energy transfer to buildings be affected if there were a short circuit in the electric grid? What about a broken circuit?</i>	(Accept all responses.)

Motivate the reading. Say, *I have a short reading about one of the worst energy crises in U.S. history. It might give us some clues about what happens when something goes wrong in the electric grid, and what can be done to prevent it.*

2 · READ ABOUT A POWER OUTAGE EVENT

15 min

MATERIALS: *Undergrounding Power Lines*

Introduce the reading. Present **slide B**. Distribute *Undergrounding Power Lines* to each student. Read the directions on the slide:

- Read about a situation in which overgrown trees caused an energy crisis that affected more than 50 million people in North America.
- As you read, underline ideas that could inform how we can make our electric grid more reliable.

Give students the remainder of the allotted 15 minutes to complete the reading and annotate it.

ADDITIONAL GUIDANCE	<i>Undergrounding Power Lines</i> introduces an engineering solution of burying electricity infrastructure underground to prevent animal damage and fallen trees from breaking or short-circuiting a portion of the grid. It also introduces the constraints that prevent this solution from being used everywhere, and gets students thinking about the equity issues inherent in access to more reliable power infrastructure.
---------------------	--

3 · INTRODUCE THE ENGINEERING DESIGN TRACKER

10 min

MATERIALS: *Engineering Design Tracker*, science notebook

Introduce the *Engineering Design Tracker*. Present **slide C**. Distribute *Engineering Design Tracker* to each student. Ask, *What strategies did you read about that engineers have tried to make the electric grid more reliable?* Listen for ideas about undergrounding power lines.

Tell students we will keep track of our ideas so we can use them to inform solutions we might consider in our own community. Tell them we will fill in the first box together, but they will then fill in the rest on their own.

The Unit 11.1 *Engineering Design Tracker* includes three boxes for each entry:

1. What are the new **science ideas** we figured out that could make the systems in our community more reliable?
2. How could engineers designing a power grid for a community **apply these ideas** in practice?
3. What **constraints** might make it hard for engineers to apply these ideas?

Hold a brief discussion to answer Part 1 on the tracker. Have students write the number 3 in the first column to indicate which lesson we are in. Then ask them to consider what might go in the first box. Listen for an ideal response like this one: “A *broken circuit* means energy will not flow. A *short circuit* can cause most or all energy to go to the surroundings. Both of these can prevent energy from transferring to our community. They can be caused by storms that knock down trees, or even by animals.” *

Brainstorm ideas for Part 2. Give students about five minutes to work with a partner to answer Part 2. Then have them share out. Listen for ideas about putting lines underground. Students may also include design solutions from Lesson 2, such as insulated wires, or electrical boxes.

SCIENCE NOTEBOOK



Students will keep two trackers for this unit. The *Progress Tracker* was begun in Lesson 1 for keeping track of the models we will build throughout the unit. The *Engineering Design Tracker* is introduced in this lesson. These handouts are three-hole-punched for insertion into students' science notebooks, either behind or in front of the regular *Progress Tracker*, or in a separate section. Please see the callout in Lesson 1 for guidance on setting up students' notebooks.

Consider the constraints on design solutions. Say, *Constraints are limitations on a design. For example, one idea for a design solution might be to build every home their own personal power plant. Why don't we do that? What constraints, or limitations, make this difficult or impossible?* Listen for students to suggest the cost of the materials, the space, the people who must work at the plant, and so forth. *

ADDITIONAL GUIDANCE

Constraint is a term we often hear along with *criteria*. *Criteria* are things a design needs to have or do to be successful--its requirements. *Constraints* are limitations on a design.



Complete Part 3 and share out. Give students a minute to complete Part 3 before inviting them to share their ideas. A sample completed *Engineering Design Tracker* is shown below.

* ATTENDING TO EQUITY

Supporting emergent multilinguals: Before students engage in whole-class discussion, it can be helpful to first provide them with the opportunity to work with others--in pairs, triads, or small groups--on ideas related to their reasoning. These smaller group structures can be especially helpful for emerging multilingual students because they offer (1) a chance to engage in sensemaking with peers and (2) a space to use linguistic and nonlinguistic resources to express ideas, and to learn from other students' uses of these resources.

* ATTENDING TO EQUITY

Supporting emergent multilinguals: The word *constraints* was used in multiple middle school units including *OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down?* (*Cup Design Unit*), *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem?* (*Homemade Heater Unit*), and *OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other?* (*Collisions Unit*), but it is a new word in this unit. Teachers can support all students, particularly emerging multilingual students, in forming a deeper understanding of newly “earned” vocabulary by representing the term in multiple ways. For example, students can (1) write the term, (2) draw a representation of the term, (3) use their own words to write an explanation for what the term means, and (4) use the new term in a sentence.

Lesson #	What are the new science ideas that we figured out that might affect our community solutions?	How could engineers designing a power grid for a community apply these ideas in practice?	What constraints might make it hard for engineers to apply these ideas?
3	<i>A broken circuit means that energy will not flow. A short circuit can cause most or all energy to go to the surroundings.</i> <i>Both of these can prevent energy from transferring to our community. They can be caused by storms that knock down trees, or even by animals.</i>	<i>Engineers can move power lines below ground to prevent damage from animals, ice, wind, and trees.</i> <i>Engineers could add insulation to wires to prevent short circuits caused by animals.</i> <i>Engineers protect infrastructure inside boxes.</i>	<i>The biggest constraint to moving power lines below ground is cost. It's over 10 times more expensive to install power lines underground versus above ground.</i> <i>Another constraint is access to the power lines. It is more expensive to repair underground power lines because they are harder to access.</i> <i>Underground power lines can still be damaged by flooding or earthquakes.</i>

KEY IDEAS

Purpose of this discussion: This discussion is intended to help students connect their thinking about energy transfer to the long-term work of redesigning our electric grid. Use the reading to frame the *Engineering Design Tracker* as a place to think about real impacts on real people. This process will span the entire unit.

Listen for these ideas:

- Short circuits can cause energy transfer to the surroundings and loss of power in the system, which can affect millions of people.
- Specific engineering solutions can help, such as burying power lines underground or protecting infrastructure from hazards.
- There are constraints inherent to every design solution, such as the high cost of burying power lines underground.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

Look for students to recognize and write about **constraints** (e.g., cost, space, etc.) on undergrounding power lines that will make it more difficult for communities to implement that design solution. (SEP: 6.5; Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)

What to do: If students suggest aesthetic or environmental impact as constraints, invite them to add those in their *Engineering Design Trackers*, but push them to include ideas that connect to recent classwork as well. If students do not identify constraints for burying power lines underground during this discussion, ask probing questions such as, *Why do you suppose not all communities have moved their power lines underground? What might prevent a community from burying power lines?*

Building toward: 3.B.1 Evaluate the impact of empirical data about energy supply and demand from Texas in February 2020 and 2021 to identify patterns, and evaluate how scientific knowledge and constraints impact possible solutions. (SEP: 4.5, 6.5; DCI: PS3.B.4; CCC 1.5, Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)

4 · DEVELOP A MODEL TO REPRESENT ENERGY TRANSFER IN THE SYSTEM

12 min

MATERIALS: None

Motivate the transition to a different energy transfer model. Present slide D. Ask, *How can the ideas from the reading help us make progress on understanding what happened in Texas?* Listen for students to suggest that maybe a short circuit caused energy to transfer to the surroundings.

Suggest looking back at our Consensus Model from Lesson 1. Review the representations we included in that model, including:

- the sticky notes representing the three systems (energy source, transportation/distribution, and destination)
- the arrows representing energy transfer

Develop conventions to translate the sticky notes and arrows to paper. Present slide E. Say, *We used sticky notes in Lesson 1 to represent systems. Let's come up with a representation of energy transfer that we can draw in our notebooks.* Then use the slide prompts to elicit student ideas. *

Suggested prompt	Sample student response
<i>How can we easily represent the main components or subsystems of the system?</i>	Draw them as squares, like the shape of the sticky notes we used in Lesson 1. Draw them as circles.
<i>What can we do to show how energy transfers between them?</i>	Draw arrows, like we did in Lesson 1.
<i>What can we use to bound the whole system?</i>	Dotted lines, like we did in Lesson 1.

As students share, draw a rough model like the one from Lesson 1 on the board, using these agreed-upon conventions. Make sure to include any additions from Lesson 2 that students think are important, such as substations. We recommend representing parts or subsystems with boxes and energy transfer with arrows.

ADDITIONAL GUIDANCE

Students may make a connection between Lesson 2's circuit diagram and the directionality of energy transfer in the grid. If they think that energy must return to the power station because a circuit is a circle, take a moment to explore this idea. Use probing questions to clarify the difference between a circuit diagram and an energy transfer diagram, such as:

- *Did our circuit diagram model energy transfer?*
- *Do we have any evidence that energy goes back to the power plant?*

If students are still convinced that the energy must flow in a circle, add any arrows returning to the power plant in red with question marks to indicate this is something we are not sure about yet.

Use the new representation to model a short circuit, with energy lost from the system. Present slide F. Use the energy transfer model on the board to elicit student ideas about how to represent the energy crisis in 2003 that began in Ohio, and spread across the entire Northeast and into Canada. Highlight ideas about energy loss, and create controversy around how to represent energy lost to the surroundings. Then bring the class to consensus on representing energy loss as arrows that cross the dotted boundary line of the system, and write the word "Surroundings" outside this line.

* SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

Systems thinking plays a central role in how scientists analyze the flow of energy and cycles of matter that characterize a phenomenon. One of the main challenges students face when using systems thinking is defining what belongs to the system under investigation and what belongs to the surroundings. To support development of systems thinking throughout this unit, we suggest using similar prompts whenever we analyze a system. By using similar prompts across contexts, students will understand that defining the boundaries of any system depends on the question being answered.

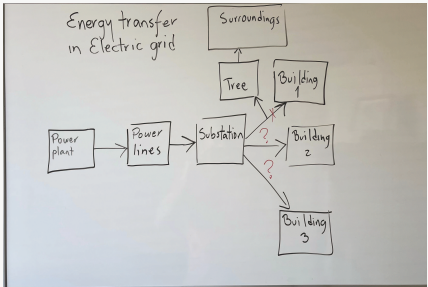
Ask questions about the quantity of energy transferring to various parts of the system. Point to a place in the model where energy will no longer transfer into a building because of a short circuit. Use the prompts below to start a class discussion.

Suggested prompt	Sample student response
How much energy is transferring into this building?	No energy is transferring to the building, because the power is out. Maybe some energy is transferring, but it's not enough to keep the lights on.
What evidence do we have for this?	We saw that in Lesson 2 with Electric City.

Put an X on the arrow leading directly to that building to show there is no energy (or not enough) transferring. Then use the prompts below to focus students' attention on what happens to the energy transferring into the system when the energy transferring into the building is zero (or close to zero).

Suggested prompt	Sample student response
Does the amount of energy transferring into the system also go down to zero, or does it stay the same? Or does it do something else?	Accept all responses.
What evidence do we have to answer that question?	Accept all responses.

At the end of this discussion, your model should look something like the image at right. Use question marks to indicate places of confusion or disagreement. Confusion around what happens when energy enters the system will motivate the next several lessons, so be sure to highlight this uncertainty around where the electricity comes from.



5 · NAVIGATE: EXIT TICKET

5 min

MATERIALS: piece of paper for exit ticket

Navigate with an exit ticket. Say, *What happened in Ohio and the Northeast in 2003 is one way an electric grid can be disrupted, and it gives us ideas about what could have happened in Texas. But just because short circuits could cause a power outage doesn't mean that was the cause in Texas.* Pose the prompt on slide G as an Exit Ticket: What other scenarios could cause no energy or not enough energy to be transferred to buildings?

End of day 1

6 · NAVIGATE

5 min

MATERIALS: None

Discuss alternative scenarios that can result in no energy transfer. Present slide H, which has the Exit Ticket prompt from last class. Say, *What happened in Ohio and the Northeast in 2003 is one way an electric grid can be disrupted, and it gives us ideas about what could have happened in Texas. But just because short circuits **could** cause a power outage doesn't mean that was the cause in Texas. What other scenarios did you consider in your Exit Tickets that could cause no energy or not enough energy to be transferred to buildings?*

Scenarios to highlight that students will model in the next activity include:

- a broken circuit to a building
- a short circuit on the path to a building
- one building (or many) using more electricity than usual
- a power plant that stops producing power

Motivate modeling multiple scenarios. Say, *It sounds like we have some ideas about how energy transfers in the electric grid. But it is a complex system, and we aren't sure about exactly how much energy goes where. Let's try to model some of these scenarios using our new energy transfer representations to see whether it can help us identify areas we want to explore next.*

7 · MODEL ENERGY TRANSFER IN VARIOUS SCENARIOS

25 min

MATERIALS: *Energy Transfer Scenarios*, blue pen



Model energy transfer in five scenarios. Ask students to organize into pairs. Distribute *Energy Transfer Scenarios* to each student. Ask students to work together on this task. They can either model together on one handout and then both copy the finished model onto their *Progress Tracker* after receiving peer feedback, or work together on individual models, and choose one version to swap for feedback, and then copy into *Progress Tracker*.

Read aloud the instructions described in the handout, and invite students to ask clarifying questions before you move on. This handout includes the following scenarios students will be asked to model:

- **Scenario A:** Normal operations--all three houses use about the same amount of energy.
- **Scenario B:** A tree falls on a line to House 3, and energy is lost from the system. All three houses experience a blackout.
- **Scenario C:** A tree falls on the line, breaking the circuit to House 1, and House 1 experiences a blackout. House 2 and House 3 use the same energy as usual.
- **Scenario D:** House 3 begins using twice as much energy as House 1 and House 2.
- **Scenario E:** What other situation could cause changes to the grid that could lead to a blackout? Possible scenarios students might choose include:
 - A power plant stops producing power.
 - A power plant produces less power than usual.
 - Many houses begin using twice as much energy as usual.

Present slide I and use the slide prompts to describe the task:

- *Model Scenarios A-E to see whether any of them could explain what happened in Texas.*
- *Make sure to model how much energy is getting to each house.*
- *Add question marks (?) in parts of the model(s) you are not sure about.*

Give students 15 minutes to complete their models.

**ALTERNATE
ACTIVITY**

The goal of this task is threefold: (1) to clarify that a short or broken circuit is not the only possible explanation for what happened in Texas, (2) to practice our new energy transfer modeling conventions, and (3) to encourage students to begin quantifying energy transfer in the system to answer their questions and understand the impact of energy loss.

If the class comes up with alternative scenarios, they can model them in their notebook alongside, or instead of, Scenarios A-D. Scenario E also provides space for one alternative.

Compare energy transfer models with another pair. Present **slide J**. Instruct students to choose only one of their copies of *Energy Transfer Scenarios* to swap with another student pair and follow the slide’s instructions to annotate similarities, differences, and uncertainties in their peers’ models. Give students about 5 minutes to complete their annotations. After students get their own handouts back, give them an additional five minutes to process and incorporate feedback into their own models.

Discuss scenarios and identify areas of uncertainty in the models. Present **slide K** and use the slide prompts to elicit student ideas in a brief whole-class discussion.

Suggested prompt	Sample student response
<i>How did you clearly show how much energy goes to which subsystems?</i>	Using numbers. Using percentages. Using symbols that help us quantify how much energy goes out of and inside each part.
<i>Do we know how much energy goes to which subsystem?</i>	We need data to figure this out.
<i>Using the evidence we currently have, which models could explain what happened in Texas?</i>	(Accept all responses.)

Collect *Energy Transfer Scenarios* after this discussion.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Modeling energy transfer across more than one system (e.g., the power plant, substation, and buildings) and using question marks to indicate areas of uncertainty. (SEP: 2.3)
- Using numbers or symbols to quantify energy coming in and out of various parts of the system (e.g., the buildings, power plant, and/or substation). (CCC: 4.3)
- Indicating that the energy coming into the substation from the power plant is equal to the total energy leaving the substation to buildings and the surroundings. (DCI: PS3.B.2)
- Models for Scenarios A and B include an arrow to indicate a connection between parts of the electric grid and the surroundings, to account for the energy loss in the system. (CCC: 4.3)

What to do: Walk through the classroom as students complete their energy transfer models. Use the following prompts to encourage students to identify areas of uncertainty and to support their ideas with evidence we have seen.

- *What do you think you will see when...?*
- *Do we have any evidence to support that idea?*
- *What assumptions are you making about the energy used by...?*

Call on students' previous knowledge about how energy cannot be created or destroyed as they try to add numbers to their models. Say, *I see that ___ energy goes into the substation, but only ___ comes out. Where did that extra ___ energy go?*

Encourage students to explore the limitations of their models. Say, *Are you certain of the exact amount of energy that transfers in your models? What are you certain of? Where can you use a question mark to show you're less certain?*

Building toward: 3.A Develop and use a model based on evidence from our investigation in Lesson 2 to illustrate the energy flow between components of the electric grid system and energy loss from the system as a possible cause of the crisis in Texas. (SEP: 2.3; DCI: PS3.B.2, PS3.D.1; CCC: 4.3)

8 · ANALYZE GRAPHS OF FORECASTED ELECTRICITY DEMAND

15 min

MATERIALS: *Electricity Demand Forecast*

Introduce supply and demand data. Present **slide L**. Tell students that you have some data that might help us explore some of our questions. Tell students the data is from a government website that tracks energy data across the country.

Give students a minute to read the text on the slide, or read it aloud: *We have data on how much electricity was available in the Texas grid during the February 2021 storm (energy supply), and how much electricity was forecast to be used during that time (energy demand).*

Then ask students to turn and talk about the prompt on the slide: *How could this supply and demand data help us make progress on our questions about what happened over this period?* *

Introduce the Identify and Interpret (I²) Strategy. Present **slide M**. Tell students we will look at the energy demand forecast first. Say, *We are going to use a strategy for analyzing this data, first as a class, and then with a partner.* Distribute *Electricity Demand Forecast* to each student. Explain that we will look at the data from February 2021, but that we also have data from February 2020 to compare it to.

Identify salient parts in the data. As a class, discuss the x- and y-axes, making sure students understand what the graph is representing. Ask a volunteer to read “Step 1” from the handout:

- Identify any changes, trends, or differences you see in the graphs. Draw arrows and write a “What I see” comment for each arrow.
- Keep your comments short. Focus only on what you can see. Do not explain the meaning yet.

Have students talk with a partner to identify these elements and annotate their handouts. Then invite a student pair to share one of their noticings. If possible, help these volunteers locate their noticings on the slide image, so the rest of the class can see. Ask other pairs to rephrase this noticing; for example, ask, *Who thinks they understand what ___ is saying, and can say it in their own words?* Give the class a few moments to write this observation in the handout.

Remind students not to try to explain the meaning of that observation yet, only identify it and describe it. Their observations might include:

- The electricity demand forecast increases up and down over time in almost regular intervals.
- The highest demand was when the temperature was the lowest.
- The electricity demand forecast is much higher in 2021 than in 2020.

Interpret the meaning of the graphs. Present **slide N**. Ask another volunteer to read “Step 2” from the handout:

- Interpret the meaning of each “What I see” comment by writing a “This means” comment. Do not try to interpret the whole graph or figure.

To frame this analysis, read the slide prompt aloud: *What could have caused an increase in the energy demand forecast in February 2021 compared to February 2020?* Listen for responses such as:

- Temperatures can affect how much electricity people use throughout the day.
- People were using more electricity during the storm.
- The power company thought people would use more electricity when it got cold.
- Lots of people turned on their heaters, just like the example we modeled.

ALTERNATE ACTIVITY

If time allows, show your class an example of the live forecast for your own community during the class. Access <https://www.eia.gov/electricity/gridmonitor/dashboard/custom/pending> and display it on-screen so everyone can see it. Search your region on the map. Doing this will help students see that the energy demand forecast goes into the future. Use <https://www.youtube.com/watch?v=ocu9UKskKaM> for guidance of how to find the electricity demand in a particular region.

* ATTENDING TO EQUITY

Supporting emergent multilinguals: Take time to break down some of the new words arising in this lesson, especially if you have emergent multilingual learners in your class. Ask students, *Where have you seen the word “demand” before? “Supply”? “Forecast”?* Make connections to weather forecasting to help students understand that this is a prediction. If possible, ask students to translate these words into other languages they might speak, and look for cognates.

ADDITIONAL GUIDANCE

Note that the graphs' vertical axis is labeled "Energy" in megawatt-hours (MWh). A megawatt-hour is a measure of finite energy that can be converted to joules. These graphs show how much energy was demanded each hour. That means the y-axis is in fact indicating "energy per hour." Energy per hour is technically a measure of power, rather than energy, and thus could be converted to watts (joules per second), but the industry standard is to describe this measure in terms of MWh. The EIA website makes this distinction, but we do not recommend trying to make this distinction with students.

Navigate. Ask students to hold onto *Electricity Demand Forecast* for the next time we meet, and forecast that we will look at data on how much energy was actually produced next time.

End of day 2

9 · NAVIGATE

5 min

MATERIALS: None

Remind students about the graphs we analyzed last time. Present **slide O**. Ask students to take out their copies of *Electricity Demand Forecast*, and spend a couple of minutes discussing the patterns they identified with a partner, and the two questions on the bottom of the slide (see the table below for these prompts).

Dig deeper into what it means to forecast demand. Point out that the demand data is a forecast of how much energy people will use. Use the prompts below to guide a short discussion about how power companies might produce this forecast.

Suggested prompt	Sample student response
<i>How do you think power companies make these forecasts of demand?</i>	People could be expected to use more or less energy. During the night people probably use less electricity, so the prediction would go down. Maybe the weather could affect how much electricity people usually use.
<i>What sorts of decisions might the power companies make using these forecasts?</i>	If people are going to need more electricity for any reason, the power plants will need to produce that energy. If there are multiple power plants, they might turn off one that isn't needed when people aren't using much energy.

10 · ANALYZE GRAPHS OF ELECTRICITY PRODUCTION AND DEMAND

10 min

MATERIALS: *Electricity Production*

Introduce electricity demand forecast and production. Present **slide P**. Distribute *Electricity Production* to every pair of students. Say, *Now that we better understand how much energy demand was predicted to increase, let's see what happened to the production of electrical energy. This graph is more complicated because it's actually two graphs in one. The blue line shows the same demand forecast we saw already, but there is also a yellow line. This yellow line shows the actual electricity production, or the supply, from power plants in the Texas grid.*

Identify and interpret patterns in pairs. Encourage students to use the Identify and Interpret (I²) Strategy again, and to direct their thinking toward one feature of the graph at a time. After a few minutes, present **slide Q** and instruct student pairs to begin discussing the questions on the slide (in the table below). Move around the classroom and support students' discussions.

Suggested prompt	Sample student response
What differences do you notice between supply and demand?	The yellow production graph goes down while the blue forecast graph goes up. The yellow and blue graphs separate in 2021, but they stay together in 2020. The temperature got really cold for Texas on February 15th. This is exactly when the graphs separate from each other.
What do you think it means?	Supply didn't match demand.

11 · DISCUSS ABOUT ENERGY SUPPLY AND DEMAND IN A SCIENTISTS CIRCLE

25 min

MATERIALS: *Energy Transfer Scenarios, Discussion Mapping Tool*

Form a Scientists Circle. Ask students to bring their models and chairs and sit in a Scientists Circle.

Introduce the discussion mapping tool. Display **slide R**. Say, *We are going to use a tool today to map our discussion. This will help us think about how we can all work together when we are discussing new ideas to make sure our participation is equitable.* Then pose the prompt on the slide: *What do we hope we will see in a completed discussion map?* Listen for students to say they hope the map has lots of connections between lots of students and is not clustered in one area.

Establish student volunteers. You will need four student volunteers for this discussion: two facilitators and two discussion mappers. Consider reaching out ahead of time to students who may want to fill these roles. Give a copy of *Discussion Mapping Tool* to the volunteers who will be mapping. These students should switch off halfway through so that both students get a chance to participate fully.

ADDITIONAL GUIDANCE

Discussion Mapping Tool provides a visual representation of the conversation patterns within the class. Use lines to track how the discussion moves between speakers, including yourself. After you track the first several moves, pause to show students what the map looks like. Have the volunteers map the rest of the discussion (this is a way to involve a student who is less comfortable speaking publicly). Each time you use the tool, rotate the student responsible for recording. Although the tool includes codes to mark various types of contributions, you may want to track only discussion patterns the first few times you use it. As students become comfortable with mapping, you can add codes.

After framing the questions, take a seat in the circle as a co-participant rather than a facilitator.



Build understanding about supply and demand mismatch as a class. Present **slide S** and give student partners several minutes to talk about the questions on the slide. Then use the prompts below to structure a whole-class conversation about supply and demand.

Suggested prompt

In the graph from 2020, supply and demand vary together very closely. Why do you think that is?

It turns out power plants can increase or decrease their output, depending on the demand. But if that is the case, why do you think there is such a big gap here when the temperatures dropped?

What do you think was happening in people's homes at this moment when the temperatures dropped, and supply and demand didn't match anymore?

How does this data connect to our models from Scenarios A-E?

Sample student response

Because power plants can make more when people need more.

Because they had forecasted it.

In 2021 the production couldn't keep up with the demand. The power plants were making way less energy than people wanted to use.

I think the power plants weren't able to put out enough electricity, so they couldn't actually increase their output depending on demand.

People probably couldn't heat up their homes.

People lost power in some areas because there was not enough electricity for everyone.

Maybe some people started using more electricity and the system could not keep up with this demand.

In our models, the energy coming out of the power plant always equaled the energy coming out of the substation and going into houses or short circuits.

The yellow line is the number coming out of the plant, but the other line is the total number going into the houses and other buildings.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Concise descriptions of patterns (similarities, trends, or changes) presented in the graphs, such as:
 - the rapid increase in electricity demand from February 14 to February 17 of 2021
 - the almost perfect match of supply and predicted demand in 2020
 - the mismatch between energy demand and supply during the energy crisis in 2021
- Reasonable inferences about patterns that emerge from the data, such as:
 - People used more power when it got cold because they needed to heat their homes.
 - Power companies make enough supply to match demand when the system is functioning properly.
 - When supply does not match demand, people will lose power. (SEP: 4.5; DCI: PS3.B.4; CCC 1.5)

What to do: The graph of energy demand forecast is less complex than the others, because it only shows one line. Use this first graph as a chance to spot students who may have trouble as the graphs become more complex. Encourage students to use the Identify and Interpret (I²) Strategy. Say, *Where do you notice a similarity or a change? Draw an arrow pointing to only that one part of the graph, and focus on it.*

Building toward: 3.B.2 Evaluate the impact of empirical data about energy supply and demand from Texas in February 2020 and 2021 to identify patterns, and evaluate how scientific knowledge and constraints impact possible solutions. (SEP: 4.5, 6.5; DCI: PS3.B.4; CCC 1.5, Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)

Decide which scenarios better explain what happened in Texas. Present slide T. Ask students to go back to the energy transfer models they completed in *Energy Transfer Scenarios* the previous day. Give student pairs a couple minutes to decide which of Scenarios A-E help explain the data in the graphs.

Choose two scenarios and model them as a class. Invite the two designated facilitator student volunteers to the front of the room. One student will be leading the discussion and calling on student volunteers. The other student will be recording student ideas. Work as a class to choose two energy transfer scenarios and model them together. Use probing questions to push students toward choosing scenarios in which the problem is about supply and demand.

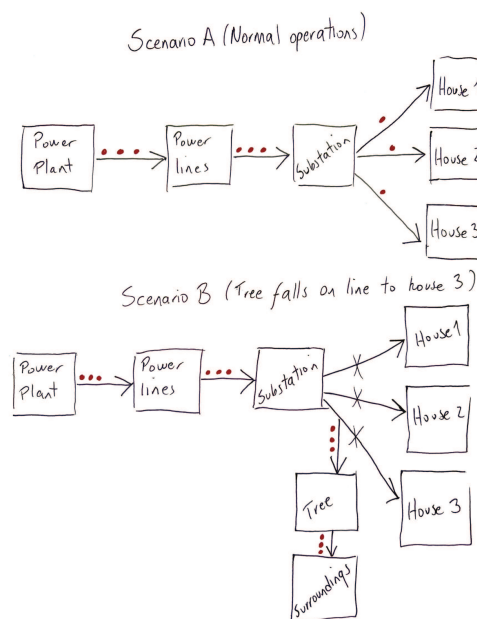
For example:

- We suspected a mismatch between supply and demand was behind the 2021 outages in Texas. Is that scenario about supply and demand?

At first, the volunteer leading the discussion may only be comfortable calling on students without following up with questions. Let them own this role, but support the discussion by modeling follow-up questions. If possible, suggest some or all of the following prompts:

- Do we all agree with that?
- Do we have evidence to support that idea?
- How did you arrive at that conclusion?
- Does it always work that way?

Your model will look different depending on which scenarios the class decides to model. See the example at right for what one of your models might look like.



Date Source: US Energy Information Administration

12 · NAVIGATE: EXIT TICKET

5 min

MATERIALS: blank sheet of paper, science notebook, *Discussion Mapping Tool*

Reflect on the discussion map. Present **slide U**. Display the discussion map by passing it around, putting it under a document camera, or snapping a photo and projecting it. Give students a few minutes to individually observe the map and write any patterns they notice in their science notebook.

Ask, *Looking at this map, how do you think we are doing on our progress toward what we wanted to see in our Community Agreements in the “Equitable” category?* Accept all ideas.

Then say, *After looking at this map, which Community Agreements should we prioritize? What are some things that we should consider during our discussions to make sure everybody plays a role, and our discussions are more equitable?* * Listen for responses such as:

- We should ask questions and respond to each other instead of directing our responses to the teacher.
- We should invite people into the discussion who have not had chances to add to the discussion.
- We should monitor our airtime and give other people time to talk.

ALTERNATE ACTIVITY

If there is time, consider asking students to gather around the Community Agreements poster, and use sticky dots or check marks to indicate which agreements they think we should prioritize.

Add new terms to Personal Glossaries. Present **slide V**. Ask students to share out a few ideas about what new terms might be important to keep track of. They may suggest *supply*, *demand*, *criteria*, and *constraint*. Give students a few moments to add these words to their glossaries.

Brainstorm where to go next with an exit ticket. Present **slide W**. Distribute a piece of paper to each student and ask them to use it to write their ideas in response to the slide prompt: *What part of the electric grid system do you want to investigate next to determine what might have happened to decrease supply in Texas in February 2021?* Have students turn in their exit tickets before they leave.

* ATTENDING TO EQUITY

Building classroom culture: The goal of this reflection is to notice whole-class patterns and decide how to move discussions forward as a community. Avoid addressing the contributions or behaviors of specific students. If they are brought up, prompt students to return to the class-level patterns we observed, saying, *Let’s look at the whole map. What suggestions would support our whole class community?* This is also an opportunity to remind students that *Discussion Mapping Tool* captures only spoken contributions, and to explicitly state that nonverbal participation and listening closely are also valued contributions.

Additional Lesson 3 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

This is the CCMS related idea that is used to support sensemaking in this lesson.

Number and Quantity

- **CCSS.MATH.CONTENT.HS.N-Q.2 Quantities:** Define appropriate quantities for the purpose of descriptive modeling.

This lesson introduces a tool, the Energy Transfer Model, for making sense of how energy flows in a system, and the types of matter interactions associated with it. This model uses a simple quantitative approach to make sense of energy transfer and to determine whether the amount of energy increases or decreases as the energy flows across. Quantifying energy will support students in thinking about conservation of energy, while helping them draw connections between the stability of the system and its reliability.

Before defining quantities for the purpose of describing energy transfer in the system, you might want to ask students to use a semi-quantitative approach, identifying whether energy increases or decreases in magnitude as it transfers from one component to the next.

LESSON 4: What makes an energy source reliable?

PREVIOUS LESSON We read about an energy crisis that began in Ohio, and a strategy used by engineers to prevent short and broken circuits in power lines. We kept track of our ideas for design solutions in the Engineering Design Tracker. We developed a new representation to model energy transfer through systems. We analyzed data about electricity supply and demand in Texas, and we noticed a drop in supply during the blackout. We brainstormed about what could have caused that drop in supply.

THIS LESSON

INVESTIGATION

2 days



US Marine Corps, Pfc. J. Handeland

We look at energy sources used in Texas, and consider what we know about each. We use informational cards to seek additional information about specific sources of energy to help us figure out which source might be responsible for the drop in supply we discovered in Lesson 3. We rank the sources by reliability, but realize that this criterion is hard to quantify. We look at several data representations from the 2021 Texas crisis to analyze how each energy source performed. We use a new tool called Decisions Matrix to keep track of how well each source meets criteria we think are important.

NEXT LESSON

We will use diagrams of power plants to figure out how they transfer energy into wires, which makes us wonder what is happening inside generators. We will dissect a generator, then build our own, and use compasses to investigate fields. Lastly, we will model energy transfer through fields inside our generators, and make connections between matter and energy to refer to as we move forward.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

4.A Analyze multiple types of data to identify characteristics of energy sources derived from Earth's systems that increase the reliability of the energy grid (a criterion for success), given that for the system to remain stable, it must be designed for energy supply to meet energy demand. (SEP: 4.6; DCI: ESS3.A.2; DCI: PS3.B.4; CCC: 7.4)

WHAT STUDENTS WILL FIGURE OUT

- The energy used to create electricity in a power plant comes from Earth's systems.
- Making decisions about complex societal issues like energy production requires defining criteria for success that might not be straightforward or easy to quantify.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		NAVIGATE Based on exit tickets from Lesson 3, take a look at energy sources in Texas, consider what we already know about energy sources, and discuss what we want to know more about.	A-C	<i>Texas Power Stations</i> (optional)
2	15 min		RANK ENERGY SOURCE CARDS Students rank <i>Energy Source Cards</i> using criteria that they believe contribute to reliability.	D-E	<i>Energy Source Cards</i>
3	5 min		CONDUCT A RANKING GALLERY WALK Conduct a quick gallery walk of card rankings, asking students to take notes on what factors they think other groups used in their decision-making.	F	<i>Energy Source Cards</i>
4	15 min		LEAD AN INITIAL DISCUSSION ABOUT RELIABILITY Discuss patterns from the gallery walk as a class. Make a poster about the factors that are important for reliability. Develop a class working definition of <i>reliability</i> .	G-H	chart paper, markers
5	2 min		NAVIGATE: EXIT TICKET Navigate with an exit ticket to motivate looking at additional data about how the energy sources performed in Texas in February 2021.	I	piece of paper for an exit ticket
<i>End of day 1</i>					
6	2 min		NAVIGATE: TURN AND TALK Navigate with a Turn and Talk that connects to the exit ticket from day 1. Motivate looking at additional data about how these energy sources performed in Texas in February 2021.	J	
7	15 min		ANALYZE ENERGY SOURCE SUPPLY GRAPHS Review patterns in electricity supply data as a class. Analyze graphs of electricity production by energy source in February 2020 and February 2021.	K-N	<i>Electricity Production 2021, Electricity Sources Comparison</i>
8	15 min		LEAD A BUILDING UNDERSTANDINGS DISCUSSION ABOUT RELIABILITY OF SPECIFIC ENERGY SOURCES Bring the class back together to discuss patterns in the data. Analyze the performance of different energy sources before and during the blackout.	O	
9	8 min		INTRODUCE THE DECISIONS MATRIX Revise the rankings using our new ideas. Introduce the <i>Decisions Matrix</i> and brainstorm criteria to include in it.	P-Q	<i>Decisions Matrix, Energy Source Cards</i>
10	5 min		NAVIGATE Revisit the “Moving our science thinking forward” category of our Community Agreements. Then have students turn and talk about the missing information from the <i>Energy Source Cards</i> .	R-S	Community Agreements poster (from Lesson 1), <i>Energy Source Cards</i>
<i>End of day 2</i>					

Lesson 4 • Materials List

	per student	per group	per class
Lesson materials	• <i>Texas Power Stations</i> (optional) • science notebook • piece of paper for an exit ticket • <i>Electricity Production 2021</i> • <i>Electricity Sources Comparison</i> • <i>Decisions Matrix</i>	• <i>Energy Source Cards</i>	• chart paper • markers • Community Agreements poster (from Lesson 1) • <i>Energy Source Cards</i>

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Print the *Energy Source Cards* and alternative version is available as https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282

Prepare chart paper for a poster titled:

- Factors that May Impact Reliability

Lesson 4 • Where We Are Going and NOT Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS3.B.4 Conservation of Energy and Energy Transfer.** The availability of energy limits what can occur in any system. (HS-PS3-1)
- **ESS3.A.2 Natural Resources.** All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2)

This lesson introduces a new scaffold, the *Decisions Matrix*, which students will use alongside the Engineering Design Tracker in Lesson Set 2 to make decisions about what designs they would like to advocate for in their community as the electric grid ages.

Students will encounter or co-develop definitions for the following words in this lesson: *reliability, efficiency, power, dispatchability*. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

8 min

MATERIALS: *Texas Power Stations* (optional)

Reflect on where we wanted to go next. Project **slide A**. Remind students that at the end of the last class, we completed an exit ticket. Tell them that most people wanted to know more about the sources of energy in Texas, because we saw a big drop in energy supply in February 2021.

Ask students to turn and talk about the prompts on the slide:

- What energy sources have you heard about?
- What energy sources do you expect to see being used in Texas? Why?

After 1-2 minutes, bring the class back together and elicit their ideas using the table below.

Suggested prompt	Sample student response
<i>What are some energy sources you have heard about?</i>	(Accept all responses.)
<i>What do you expect to see being used in Texas, and why?</i>	There is a lot of open space in Texas. Maybe solar? I've heard Texas has a lot of oil and other resources. Maybe those are being used.

Introduce Texas energy sources. Show **slide B**. Ask students to first notice and wonder individually about the map of energy sources in Texas. This map is also provided in *Texas Power Stations*, which can be distributed to each student if you wish. Elicit noticings and wonderings after a minute.

Expected noticings:

- There are a lot of solar power plants, wind power plants, and natural gas power plants.
- There are also some coal, biomass, and hydroelectric plants, and about two nuclear plants.
- Some areas have more of one type of power plant than another, but overall they are fairly well distributed.
- It doesn't look that different from the surrounding states.

Expected wonderings:

- Why are some power plants in some places and not others?
- Why are there only two nuclear plants?
- Why is there more of some kinds of power than others?
- Did any of these power sources fail in February 2021?

Present **slide C**. Ask students to turn and talk about the prompts on the slide. After 1-2 minutes, bring the class back together to discuss, using the table below. Accept all student ideas without judgment.

Suggested prompt	Sample student response
<i>What do you know about some of these energy sources?</i>	Coal comes from the ground, and gets burned. Windmills turn generators, and only work when it is windy. Natural gas is what we use to heat our homes. Solar uses solar cells to make electricity.
<i>Could any of these sources have contributed to the crisis in 2021? How?</i>	Maybe windmills froze. Maybe it was too cold to burn coal. Maybe natural gas pipelines froze. Maybe there was no sun because of the storm.
<i>What data could help us understand whether any of these sources might have been responsible for the 2021 crisis?</i>	Could we see how much electricity each one produced in February 2021?

2 · RANK ENERGY SOURCE CARDS

15 min

MATERIALS: science notebook, *Energy Source Cards*



Get familiar with the *Energy Source Cards* in groups. Have students gather in groups of 3-4, and distribute a set of *Energy Source Cards* to each group. Project **slide D**. Read the prompts on the slide aloud:

- *From which of Earth's systems are most of these sources extracted?*
- *What clues can you find that might help us understand which sources were unreliable in February 2021?*

Tell students to examine the cards and discuss the slide's questions for a few minutes. Move around the room to assess students' thinking as they talk.

ASSESSMENT OPPORTUNITY

What to look for/listen for: As you move around the room, listen for students to make the connection that almost all of **these sources come from Earth's systems, except solar.** (DCI: ESS3.A.2)

What to do: Use questions about specific systems (the air, the ground, the water, life) to support students in making those connections.

As students discuss the second question, listen for ideas about which factors might contribute to reliability/unreliability, including efficiency, dispatchability, power, and specific mechanisms related to the sources' production of energy; accept these ideas without judgment.

Building toward: 4.A.1 Analyze multiple types of data to identify characteristics of energy sources derived from Earth's systems that increase the reliability of the energy grid (a criterion for success), given that for the system to remain stable, it must be designed for energy supply to meet energy demand. (SEP: 4.6; DCI: ESS3.A.2, PS3.B.4; CCC: 7.4)

Rank the Energy Source Cards in groups. Project slide E and go over the directions on the slide:

- Which information do you think is the most important for determining which energy sources are reliable? Why?
- Rank the energy sources from least to most reliable, using the factors you identified as important.

Give students about 5 minutes to rank the energy sources at their tables. Ask students to write down their rankings in their science notebooks. Expect them to disagree about how to rank the sources. As students work, circulate and make note of the rankings. Ask them why they are making those decisions, and what additional data they would need to better inform their decisions.

Bring the class together. Point out that it seems groups have made different decisions regarding the energy sources we are examining.

3 · CONDUCT A RANKING GALLERY WALK

5 min

MATERIALS: science notebook, *Energy Source Cards*

Conduct a ranking gallery walk. Project slide F. Ask students to create a T-chart in their notebooks like the one on the slide. Quickly number or name each group to make it easier for students to record their notes in this chart.

Have students do a gallery walk, moving from table to table to observe the rankings of other groups. Instruct them to try to determine what factors each group used to assess the reliability of the energy sources, and write those in their chart.

4 · LEAD AN INITIAL DISCUSSION ABOUT RELIABILITY

15 min

MATERIALS: science notebook, chart paper, markers

Discuss patterns from the gallery walk as a class. Project slide G. Ask students to return to their seats. Have students share out any rankings that they noticed were different from theirs, and what they think that group was using as criteria in their ranking system. Verify the rankings with the group in question, and discuss how the class saw different factors contributing to the reliability of an energy source.

Make a poster about what factors are important for reliability. Focus attention on the last question on the slide. Prepare a new sheet of chart paper for this question, titled “Factors that May Impact Reliability”. Have students share out while you record their ideas. Listen for them to mention things like efficiency, power, dispatchability, or mechanisms related to how the resource is extracted.

Develop a class working definition of reliability. Project slide H. Ask students to turn and talk about the prompts on the slide for about 2 minutes:

- What does it mean for an energy source to be reliable?
- Why is high reliability such an important criterion for making decisions about energy?

Then bring the class back together to discuss the first prompt. Listen for students to suggest that reliability means stability, predictable change, or supply consistently meeting demand.

ADDITIONAL GUIDANCE

If students settle on a definition about stability (e.g., doesn't change much, always stays high, never goes down), push them to make a connection to the supply and demand graphs:

- In the graphs from 2020 that we looked at in Lesson 3, there were still a lot of ups and downs. Are you saying energy supply was unreliable in February 2020 as well?
- What was unique about February 2021 that meant people lost power, that can help us define reliability?

 **Discuss how we change reliability into a criterion.** Before discussing the second prompt, ask students to look back at their Personal Glossaries to remind themselves of what a criterion is; you may need to point out that *criterion* is the singular of *criteria* to support them in making that connection.

Say, *How can we reframe reliability to be a criterion we want to meet with the design of our electric grid? We don't have a way to quantify it, but we can say whether we want it to be higher or lower.* Listen for students to say we want reliability to be high.

Then ask students for their ideas about the second prompt on the slide. Listen for them to point out that power outages are dangerous, and that providing power in a predictable, stable way is the fundamental purpose of the electric grid.

Add new terms to students' Personal Glossaries. Give students a minute to add *reliability* to their Personal Glossary. They should also take the time to add words they encountered in their cards and listed on the Factors that May Impact Reliability poster, such as *efficiency*, *power*, and perhaps *dispatchability*.

ASSESSMENT OPPORTUNITY

What to look for/listen for: Students can explain that in order for the system to remain stable, it must be designed for supply to meet demand. (CCC: 7.4; DCI: PS3.B.4)

What to do: Use the crosscutting concept of stability and change to support student sensemaking. Remind students that in Lesson 3, they saw that energy supply and demand matched before the energy crisis (stability), and that the gap between supply and demand was the largest during the blackout (change). Use this framing to help students draw connections between the stability of an electric grid system and its reliability.

Building toward: 4.A.2 Analyze multiple types of data to identify characteristics of energy sources derived from Earth's systems that increase the reliability of the energy grid (a criterion for success), given that for the system to remain stable, it must be designed for energy supply to meet energy demand. (SEP: 4.6; DCI: ESS3.A.2; PS3.B.4; CCC: 7.4)

5 · NAVIGATE: EXIT TICKET

2 min

MATERIALS: piece of paper for an exit ticket

Assign an exit ticket to motivate looking at additional data. Distribute a piece of paper to each student and project slide I. Pose the question on the slide aloud as an exit ticket: *What additional data or information do we want to see that can help us figure out which energy sources contributed to the crisis in February 2021?* Have students write their name and their answer(s) to turn in before they leave.

Look at the exit tickets for students who write about the performance of those sources in Texas in February 2021, which will be a great transition into the work we do next. Take note of who these students are, and call on them on day 2 to ease that transition. However, if nobody brings this up, that is not a problem; simply take note of what students are interested in investigating next.

End of day 1

6 · NAVIGATE: TURN AND TALK

2 min

MATERIALS: None

Navigate with a Turn and Talk to motivate looking at additional data. Project slide J and read the prompt aloud: *What data about energy in Texas in February 2021 could help us figure out what went wrong, and which sources contributed to the crisis?*

Give students a minute to turn and talk about the slide's question. Listen for a variety of ideas. Then use your notes from day 1's exit tickets to call on students who wrote that they want to look at the performance of those sources in Texas in February 2021, and ask them to share out. Say, *I have supply graphs for each of the sources we have been investigating.*

However, if nobody comes up with that idea directly, that's OK. Use students' other ideas to consider creative ways to introduce that data; for example, if several students suggest that we look at "more data about whether the sources are reliable," you can motivate looking at the data next time by saying, *A lot of people wanted to know more about whether these sources were reliable. I have supply graphs for each of the sources we have been investigating. How could data about how much supply each source contributed in February 2021 help us figure that out?*

7 · ANALYZE ENERGY SOURCE SUPPLY GRAPHS

15 min

MATERIALS: *Electricity Production 2021, Electricity Sources Comparison*, science notebook

Review patterns in supply. Say, *Before we look at supply graphs for each of the sources we have been investigating, let's remind ourselves what a graph of energy supply looks like.*

Present **slide K**. Remind students that we looked at this graph in Lesson 3, and that we were concerned about the gap between how much energy was being supplied and how much energy people wanted to use. *

Then pose the question on the slide:

- *What patterns would we expect to see from a source that contributed to the drop in supply?*

Listen for students to suggest looking for a pattern that follows the pattern in the graph of supply (the yellow line). Say, *I made sure to include a graph of supply alongside the graphs for each individual source, so we can compare those patterns.*

Use a Stand and Talk protocol to find new partners. Project **slide L**. Ask students to stand up and find a partner that they have not worked with before. Once a student has found a new partner, give them *Electricity Production 2021*. Then give the partner pairs 3 minutes to make observations and formulate questions.

Discuss how the information is presented. Bring the class back together to briefly answer questions about the graphs that will allow students to dig deeper into the data in the next Stand and Talk. Then point out that this kind of data can be presented in multiple ways. Display **slide M**.

Ask students what they notice and wonder about the way this data is presented in each graph. Listen for ideas about how the stacked area graph shows the same data, but in a different way. Spend a couple of minutes checking in with students to ensure that these representations make sense to them. Guide them to compare the bottom graph with the top graph, and to reason out that the comparison shows that the amounts of energy from each source have been stacked on top of each other, not layered on top. This means that natural gas produced the most energy in this time period, and nuclear produced the least.

Analyze graphs of electricity production in February 2021. Project **slide N**. Say, *Let's compare this data from 2020, when there was no crisis, to data from February 2021, and see what we notice.* Ask students to do another Stand and Talk to find a new partner, and prepare a T-chart in their science notebook like the one on **slide N**, titled "February Data." Distribute *Electricity Sources Comparison* to each student once they have formed a new pair. Give them 5 minutes to work with their new partner to fill in their T-charts according to the slide's instructions.

As students are working, circulate among the partner pairs. Specifically, listen for ideas related to:

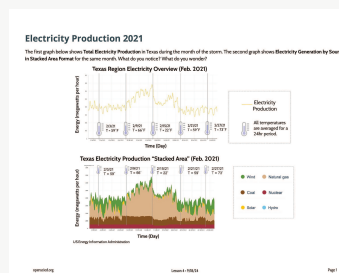
- Coal was variable in February 2020, but consistent during the blackout.
- During the blackout, natural gas increased and wind decreased. This did not happen during the previous year.
- Wind was variable and present in February 2020, but during the blackout it was almost nonexistent.
- Nuclear stayed consistent throughout most of February on both graphs.

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Take this opportunity to reinforce what we figured out in Lesson 3 related to the disciplinary core idea PS3.B: Conservation of Energy and Energy Transfer. Remind students that because energy is a conserved quantity, if sufficient energy is not supplied to the system, there is no way to create more energy for the system to function.

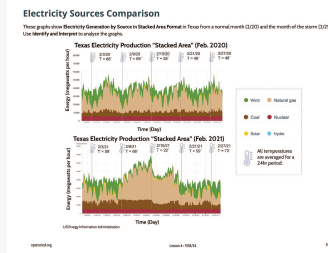
* SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Over the course of the OpenSciEd physics program, students will see multiple representations of the same data set. Make it explicit that looking at multiple representations can help scientists and engineers see new things in the data. Throughout this course, students will continue to look at a variety of graphical representations and data sets to compare, integrate, and evaluate multiple data sources to address a scientific question or solve a problem.



- Everything decreased at the same time on the 15th during the blackout.

As you move around the room, ask students how the energy production graphs compare to the prevalence of sources we saw on the Texas map (i.e., a lot of windmills, only two nuclear power plants). *



8 · LEAD A BUILDING UNDERSTANDINGS DISCUSSION ABOUT RELIABILITY OF SPECIFIC ENERGY SOURCES

15 min

MATERIALS: None

Discuss patterns in the data. Bring the class back together and present **slide O**. Use the questions on the slide (in the table below) to build understanding about important patterns in the graphs.

Suggested prompt	Sample student response
<i>How are the patterns in February 2021 different from the patterns in February 2020, and across the year?</i>	In 2020, February was relatively consistent with the other months--even in the summer, the supply stayed relatively consistent across the energy sources, with variability in natural gas. In February 2021, every source dropped significantly. Nuclear maybe stayed consistent, but it was a small amount of the total power generated. Solar is always variable, regardless of storms.
<i>How does this help us understand how each energy source may have contributed to the crisis?</i>	Windmills and natural gas both went down, and several other sources did, too. Maybe that contributed to what happened?



Motivate a second look at reliability. There is no need to come to consensus on which sources performed the best, as the answer to that question is complex. Use this conversation to expose that complexity, and establish that no single source was responsible for the crisis.

Say, *It sounds like we can't point a finger at a single energy source, because almost every source was affected to some degree, and Texas relies on each of them in different ways. But we do have some ideas about which sources might be more reliable in a crisis like this one.*

ASSESSMENT OPPORTUNITY

What to look for/listen for: Students identify patterns in the data, and can explain what they mean, relating their ideas back to reliability. (SEP 4.6)

What to do: Continually press students to justify their reasoning using the data, with prompts such as:

- *Can you show me what pattern led you to that conclusion?*
- *How does the pattern you pointed to tell us about reliability?*

Building toward: 4.A.3 Analyze multiple types of data to identify characteristics of energy sources derived from Earth's systems that increase the reliability of the energy grid (a criterion for success), given that for the system to remain stable, it must be designed for energy supply to meet energy demand. (SEP: 4.6; DCI: ESS3.A.2; PS3.B.4; CCC: 7.4)

9 · INTRODUCE THE DECISIONS MATRIX

8 min

MATERIALS: *Decisions Matrix*, *Energy Source Cards*

Return to our rankings. Suggest that it might be time to revisit our rankings from earlier, given what we now know. Present slide P. Get students back into their original groups, and make sure they still have their set of *Energy Source Cards*. Give them about 5 minutes to rethink their rankings, based on the graphs, and to reacquaint themselves with the cards.

Introduce the *Decisions Matrix*. Project slide Q. Explain that eventually, we want to be able to advocate for systems in our own community that are reliable, using lessons learned from Texas; so, we should keep track of what we figure out about how well these sources meet the criteria we set.

Distribute *Decisions Matrix* to every student. Point out that there is space in the top row for a variety of criteria, and ask students to write "High reliability" in the first box (under #1). Explain that we will record new rankings by writing the names of the energy sources in the left-hand column, and then using numbers, stars, or a rating system to record how well the sources meet that criterion.

Through a brief discussion, establish the ranking system that the class will use to evaluate the energy sources. Note that students might have seen a *Decisions Matrix* before, especially if they have engaged with middle school materials such as *Collisions Unit*, *Tsunami Unit*, or *Homemade Heater Unit*.

Add criteria to the matrix. Ask students whether we might want to include any other criteria that came up in our investigations over the past few days. Suggest that they look back at the factors they recorded in their notebooks during the gallery walk, the Factors that May Impact Reliability poster, and/or the *Energy Source Cards*. As students suggest a factor, ask them to frame the heading in terms of a criterion, e.g., "High efficiency" rather than "Efficiency." Then ask students to fill in that column.

10 · NAVIGATE

5 min

MATERIALS: Community Agreements poster (from Lesson 1), *Energy Source Cards*

Revisit the "Moving our science thinking forward" category of our Community Agreements. Present slide R. Point to the Community Agreements poster and say, *Today we did not all agree at first on how to rank the energy sources, but we managed to move forward. How did your peers help move your science thinking forward today?* Accept all ideas.

Then ask the next two questions on the slide:

- *Which Community Agreements should we prioritize in that category?*
- *What are some things we should consider next time to make sure our science thinking moves forward?*

Listen for responses such as:

- We should hold ourselves accountable for staying engaged.
- We should have fun but make sure we are being productive.
- We should be willing to throw things at the wall and see whether they stick.

ALTERNATE ACTIVITY

If there is time, consider having students gather around the Community Agreements poster, and use sticky dots or check marks to indicate which agreements they think we should prioritize.

Discuss missing information from the *Energy Source Cards*. Project slide S. Ask students to look at the energy transfer diagrams on their group's *Energy Source Cards*, and then read the slide's prompt aloud:

- What information is missing from these diagrams that could help us understand why energy sources are more reliable (or efficient, powerful, dispatchable)?
- What do you notice on the diagrams on the back of the cards?
- What information is missing from these diagrams that could help us understand why energy sources are more reliable (or efficient, powerful, dispatchable)? "

Have students turn and talk quickly about this question before leaving.

Additional Lesson 4 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

These are the CCSS related ideas that are used to support sensemaking in this lesson:

- **CCSS.ELA-Literacy.RST.11-12.2.** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- Students do this when they synthesize the information from the *Energy Source Cards* to develop the energy transfer model for each energy source.
- **CCSS.ELA-Literacy.RST.11-12.5.** Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.

Students do this by sorting the *Energy Source Cards* into different categories using the information presented in the text.

LESSON 5: Where does electrical energy come from?

PREVIOUS LESSON We used informational cards and data representations from the 2021 Texas crisis to seek additional information about specific sources of energy to help us figure out which source might be responsible for the drop in supply. We ranked the sources by reliability, but realized that this is hard to quantify. We used a Decisions Matrix to keep track of how well each source meets criteria we think are important.

THIS LESSON

INVESTIGATION

3 days



We use diagrams of power plants to figure out how they transfer energy into wires, which makes us wonder what is happening inside generators. We dissect a generator, then build our own, and use compasses to investigate fields. Lastly, we model energy transfer through fields inside our generators, and make connections between matter and energy to refer to as we move forward.

NEXT LESSON We will read about fields to help us model energy transfer more closely, focusing on transfers inside a wire. Using a simulation, we will explore how characteristics of an electrical system could influence the transfer of electrical energy, and check our results using classroom equipment. We will then refine our Engineering Design Trackers with ideas from the simulation.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

5.A Develop a model based on evidence to illustrate the energy and matter changes in a generator, including energy transfer through contact between moving parts and energy transfer at a distance through fields. (SEP: 2.3, DCI: PS3.A.2, PS3.A.3; CCC: 5.2)

5.B Design and build a generator system to transfer motion energy to light that meets agreed-upon criteria, manipulating variables and collecting data to identify failure points and improve performance. (SEP: 3.6, DCI: PS3.A.2; CCC: 4.1)

WHAT STUDENTS WILL FIGURE OUT

- Many power plants have generators, which are loops of copper wire and powerful magnets.
- Matter changes and/or motion can cause energy transfer through contact (and vice-versa).
- The motion of a magnet can generate changing fields, which can cause energy transfer at a distance (and vice-versa).
- When moving matter (e.g., pushing wind or steam) moves the magnets inside a generator, that can cause energy transfer into wires through changing fields.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE: LOOK CLOSER AT SPECIFIC POWER PLANTS Orient to thinking about what might be similar and different about the ways various sources are used to generate electricity, and what we could do to figure this out.	A	<i>Texas Power Stations</i> (from Lesson 4), <i>Energy Source Cards</i> or https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzyYDY7UJhiCPXfldhn7d1Kyc/edit#slide=id.g23f5fc8198b_O_282 (from Lesson 4) (optional)
2	20 min		INITIAL MODELS OF ENERGY TRANSFER IN POWER PLANTS Examine diagrams of a wind turbine power plant and a natural gas power plant, then develop a model of energy transfer for the wind plant as class, then in pairs for the gas plant. Then we come back together to check our thinking on the gas plant models as a class.	B-E	<i>Power Plant Diagrams</i> , chart paper, markers
3	15 min		MOTIVATE A CLOSER LOOK AT THE GENERATOR Identify the spinning generator as a key similarity between wind and natural gas power plants. Demonstrate the mini-generators with an LED, then dissect a generator to create a list of its parts.	F-G	chart paper, markers, <i>Dissecting a Generator</i>
4	5 min		NAVIGATE: EXIT TICKET Complete an exit ticket identifying possible ways that a generator transfers electrical energy and how to reverse engineer the generator.	H	8.5 x 11 paper
<i>End of day 1</i>					
5	5 min		NAVIGATE Revisit the exit ticket responses to motivate building a generator and poll them to see whether they think we can do it. Agree on criteria for success.	I-J	
6	27 min		BUILD A GENERATOR Build a generator to create enough electricity to light up two LED light bulbs.	K	<i>Building a Generator</i>
7	10 min		DEBRIEF THE GENERATOR INVESTIGATION Discuss the Build a Generator investigation as a class.	L	<i>Generator Engineering Task</i>
8	3 min		NAVIGATE: EXIT TICKET WITH A PARTNER Point out that there is energy transfer at a distance (without parts of the generator touching), and suggest experiments to investigate this.	M	
<i>End of day 2</i>					
9	3 min		NAVIGATE Make connections to magnets and energy transfer.	N	
10	5 min		REVISIT COMMUNITY AGREEMENTS: “RESPECTFUL” CATEGORY Consider how building the generator during the last class impacts our thinking about how to make our classroom respectful.	O	<i>Community Agreements poster</i> (from Lesson 1)

Part	Duration		Summary	Slide	Materials
11	20 min		BUILD UNDERSTANDING ABOUT MAGNETISM Investigate changes in the direction a compass points when it is near a generator through a series of group and class demonstrations that build on each other. Debrief the results in a Building Understandings Discussion.	P-W	chart paper, markers, Compass Experiments and Demonstrations
12	10 min		MODEL ENERGY TRANSFER IN THE GENERATOR Individually and as a class, model energy transfer in the homemade generators based on evidence from the compasses.	X-Y	8.5 x 11 paper, chart paper, markers, whiteboard and dry erase markers (alternate)
13	5 min		DISCUSS MATTER-ENERGY CONNECTION AND ADD TO THE PROGRESS TRACKER Build conceptual connections between matter and energy that will serve as the foundation for deeper understanding as students progress through subsequent units. Add to Progress Trackers.	Z	
14	2 min		NAVIGATE: EXIT TICKET Connect the generator investigations back to what happened in Texas by completing an exit ticket.	AA	8.5 x 11 paper

End of day 3

Lesson 5 • Materials List

	per student	per group	per class
Dissecting a Generator materials			• 2 mini dissecting generators • 1 super-bright red LED bulb (2V 20 mA) • 2 alligator clips
Building a Generator materials	• <i>Generator Engineering Task</i>	• 1 iron nail • 1 paper tube wrapped in 400-600 wraps of magnet wire (28 AWG) • 2 neodymium magnets (4mm x 8mm) • 2 alligator clips • 2 super-bright red LED bulbs (2V 20 mA) • string • sticky tack • power strip “building” wiring • small piece of sandpaper • safety glasses with side shields or safety goggles	• hanging weights or a full water bottle to hang from string (optional)
Compass Experiments and Demonstrations materials	• science notebook	• compass • homemade generators	• hand-crank DC generator • homemade generator • 6 compasses • 8 alligator clips
Lesson materials	• science notebook • <i>Texas Power Stations</i> (from Lesson 4) • <i>Power Plant Diagrams</i> • 8.5 x 11 paper • <i>Generator Engineering Task</i>	• <i>Energy Source Cards</i> or https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282 (from Lesson 4) (optional)	• chart paper • markers • Community Agreements poster (from Lesson 1) • whiteboard and dry erase markers (alternate)

Materials preparation (60 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Prepare chart paper for the poster you will make in this lesson:

- “What we tried/What we saw” T-chart

You will also need to create several consensus energy transfer models. Prepare whiteboard space or chart paper for these models.

SAFETY PRECAUTIONS

1. Wear sanitized safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of the activity.
2. Use caution when using sharp (tools, wires, nails, etc.), which can cut or puncture skin.
3. Use caution when operating a power drill. Operator needs a 3+ foot clearance from observers.
4. Plug power drill into GFI protected circuit and keep away from water sources to prevent shock.
5. Powerful magnets can snap together and pinch fingers. Keep the magnets far apart when not in use.
6. Use gloves to prevent pinched fingers when working with magnets.
7. Keep magnets at least 20 cm away from sensitive electronic and data storage devices.
8. Keep flammables (e.g., nail polish) away from active flames or sparks to prevent fire.
9. Use caution when working with glass bulbs. If a bulb shatters, the pieces of glassware are sharp and can cut hands. Inform your teacher!
10. Make sure all materials and equipment are returned to the appropriate location upon completing activities.
11. Wash your hands with soap and water immediately after completing this activity.

Day 2:

Dissecting a Generator

- **Group size:** Whole class.
- **Setup:** Have 2 generators available that are easily taken apart for dissection. Connect the super-bright red LED bulb (2V, 20 mA) to each generator using the 2 alligator clips to check that the generators are both functional.
- **Storage:** All materials can be stored and reused indefinitely.

Building a Generator

- **Group size:** 3-5 students.
- **Setup:** For each group, wrap 400-500 wraps of magnet wire (28 AWG) around two sections of a cardboard tube, and use the nail to poke a hole in the tube between the sections. See *Preparing Generator Materials* for details. Print a copy of *Generator Engineering Task* for all students. For guidance on how to work through this work, see <https://youtu.be/larsLDIZ6XM>.
- **Safety:** The magnets are very strong and can pinch students or shatter if they come together quickly. Encourage students to keep them apart until they attach them to the nail.
- **Storage:** At the end of each class, ask students to break down their generators so you can reuse the parts with the next class. At the end of your last class, leave the generators constructed so students can use them later in the lesson, and later in the unit. All parts can be stored indefinitely from year to year.

Day 3:

Field Demonstration

- **Group size:** Whole class.
- **Setup:** Check compasses ahead of time to ensure they all point in the same direction (which does not necessarily need to be north). One tube with wire wrapped around it should be free of magnets, so it can be used as a coil of wire.
- **Storage:** All materials can be stored and reused indefinitely.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS3.A.2 Definitions of Energy.** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)
- **PS3.A.3 Definitions of Energy.** These relationships are better understood at the microscopic scale, at which all the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). ~~This last concept includes radiation, a phenomenon in which energy stored in fields moves across space:~~ (HS-PS3-2)

Note that radiation is not treated in this unit. Students will learn about radiation in *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*.

This lesson introduces another detail to the energy transfer model: fields. The energy transfer model is a way to keep track of energy inputs, outputs, and transfers between subsystems. The diagrams of wind and natural gas power plants provide a way for students to begin to identify subsystems within the larger power plant system. The investigations using generators to create changing fields should build on students' prior knowledge about magnets, electricity, and fields.

Though students do not rigorously define *magnetic field* in this lesson, we uncover evidence that those fields exist and that they change when magnets move. We connect this to energy transfer by noticing that the generator only transfers electrical energy to wires when the magnets in the generator move.

At a macroscopic scale, we notice many examples of the motion of one component transferring energy to the motion of another component. These transfers occur through direct contact (wind pushes turbine blades, nail moves magnets, and so forth). We also note that lights turning on and objects getting warmer are similar evidence of energy transfer, though the specific mechanisms may be unclear to us for now.

Students encounter or co-develop definitions for the following words in this lesson: *generator, power plant, wind turbine, field*. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students begin to consider the interplay between matter and energy in this lesson, but they will not figure out how matter is changing inside wires or consider matter changes on a particle level. Though students identify the field propagating down the wire into the coil of wire or light bulb, the role of electrons in that propagation is not discussed. Students may identify the role of electrons or want to discuss them in the wire, but that will be the focus of the next lesson.

It is not important that students recognize interactions as forces in this unit. Students will describe energy transfers as matter changes or motion changes (e.g., fire **heats** emissions, steam **pushes** turbine, turbine **pushes** generator), building a strong foundation for considering the relationship between forces and energy transfer in the second unit of the course.

LEARNING PLAN for LESSON 5

1 · NAVIGATE: LOOK CLOSER AT SPECIFIC POWER PLANTS

5 min

MATERIALS: science notebook, *Texas Power Stations* (from Lesson 4), *Energy Source Cards* or https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282 (from Lesson 4) (optional)

Review what we know about wind and natural gas energy. Present **slide A**. Remind students that natural gas and wind were two of the sources we identified as very popular in Texas, but that we saw differences in how reliable and efficient they were, how much power they provided, and so forth. If students still have the *Energy Source Cards* or https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282 from Lesson 4 at their table, consider asking them to review these cards to help them answer.

Then have students turn and talk about the prompts on the slide:

- *What do we know about how wind and natural gas produce energy transfer in wires that would help us understand what makes each more or less reliable, efficient, or powerful?*
- *How could we figure this out?*

Elicit a few student ideas. Accept all ideas for the first prompt. For the second prompt, listen for students to suggest seeing inside power plants somehow, either through video, diagrams, a field trip, or something else.

2 · INITIAL MODELS OF ENERGY TRANSFER IN POWER PLANTS

20 min

MATERIALS: *Power Plant Diagrams*, chart paper, markers

Examine diagrams of two types of power plants. Say, *It sounds like we want to know more about what is inside a power plant. I have some diagrams that show how wind and natural gas power plants actually work. We might be able to find some clues to help us figure out what is going on in these diagrams.* Distribute *Power Plant Diagrams* to each student and present **slide B**.

Model energy transfer in the wind turbine. Suggest that we start with the wind turbine together. Ask students to respond to the prompts on the slide, as shown in the table below.

Suggested prompt	Sample student response
<i>What do you notice?</i>	Arrows showing wind motion and blades turning. Lots of different parts. A generator. Wires. An unlabeled box.
<i>What do you wonder?</i>	What is in the box? What is a generator? Why does it need to turn, and how does that make energy transfer in the wires?
<i>How could tracing matter changes in this system help us understand energy transfer?</i>	Motion is one example of how energy shows up. Energy and matter are connected somehow. When something is moving, it must have energy of motion, and that energy must have come from somewhere.

Look at the wind turbine system through the lens of matter. Project **slide C**. Ask students to consider the prompts on the slide:

- *How does matter move and change in the wind turbine system?*
- *What components and interactions represented in the diagram show this?*

Elicit student responses. Listen for students to identify the following matter motions/changes; as they do, point to them in the diagram:

- Wind is moving. (blue arrows)
- The blades and shaft are turning. (black arrows)
- We don't know what is happening in the wires.

Some students may know that electrons are moving in the wires. Tell them this is an interesting idea, and ask them what evidence we see in the diagram for that matter change. Then say, *It's not in the diagram, but let's keep that idea on the table and come back to it, because it could help explain what's happening if we zoomed in on those wires. Let's think at a larger scale for now, and then we'll zoom to a particle scale afterward.* *

* ATTENDING TO EQUITY

It is important to validate the ideas of students who feel like they are 10 steps ahead, and to make it clear that these ideas are important contributions. Remind them of the question we are trying to answer right now, and ask them to record their idea on a whiteboard, blackboard, or piece of chart paper in the classroom for us to come back to when it will help us answer our questions.

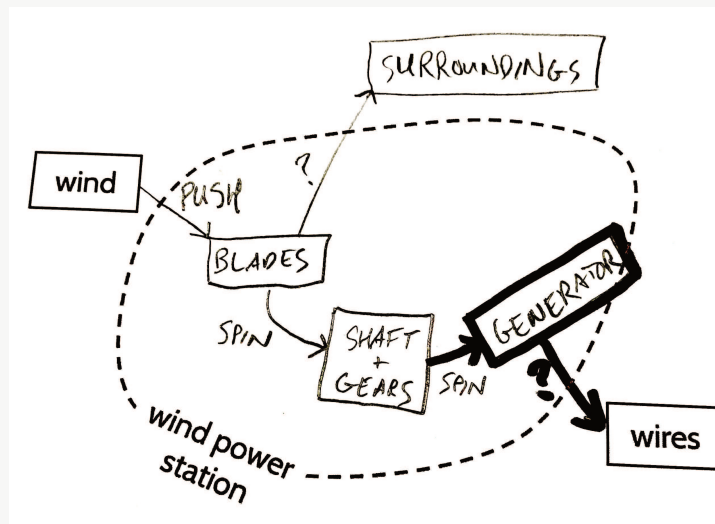
Look at the wind turbine system through the lens of energy transfer. Project slide D. Ask students to think about the prompts on the slide for a moment:

- How does energy transfer between components in the wind turbine system?
- How do we know this from the diagram?

Create an energy transfer diagram as a class. Elicit student ideas in response to the slide's prompts. Listen for them to suggest that energy transfers from the wind, to the blades, to the shaft. Suggest that we keep track of this using our energy transfer conventions, and begin to sketch out a class model on a blank sheet of chart paper.

Problematize how the generator works. Students' ideas will become less concrete as they describe the generator. One primary goal of this modeling is to discover that we don't yet know exactly how a generator works. To show this, put a question mark on an arrow from the generator to the wires.

The completed model may look something like the example below.



Model energy transfer in the natural gas plant in pairs. Project slide E. Ask students to look at the “Natural Gas Power Plant” diagram on *Power Plant Diagrams*, and then, in partners, to go through the same steps we did as a class to track how matter moves (or changes) and infer how energy transfers. Give them 5 minutes to sketch an energy transfer model on the back of *Power Plant Diagrams* and discuss the question on the slide: *How are the matter moves/changes you identified related to energy transfer?*

As students work, circulate and look closely at their progress, using their diagrams as a formative assessment. If students are having trouble getting started, prompt them to think first about matter in the system.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students should **use our box and arrow conventions** and label the arrows with at least one action word to describe energy transfer. (SEP: 2.3)
- **Energy transfer arrow labels should describe interactions**, even partially. These **energy transfers will generally manifest as matter changes or motion changes** (e.g., fire **heats** emissions, steam **pushes** turbine, turbine **pushes** generator). It is not important that students recognize interactions as forces in this unit. (CCC: 5.2, DCI: PS3.A.2)
- Students will likely not yet have a clear idea of **how energy transfer manifests in the wires**. This uncertainty will motivate the investigations in Lesson 6. Rather than pushing them to figure this out now, encourage them to highlight this limitation of their model by putting a question mark on that arrow. (DCI: PS3.A.2)

What to do:

If students are confused about which components are important, direct them to the labeled parts of the diagram. Use probing questions for which those components are a valid answer, such as: *Where does the energy start? What does the gas transfer energy to? How does the plant use the energy from the fire--where does it transfer?*

Use similar questions as in the previous discussion to elicit ideas for the model:

How do we know that there is energy in the ____?

Where is energy being transferred from the ____ to the ____? How?

What changes do we see in matter (or in motion of matter)?

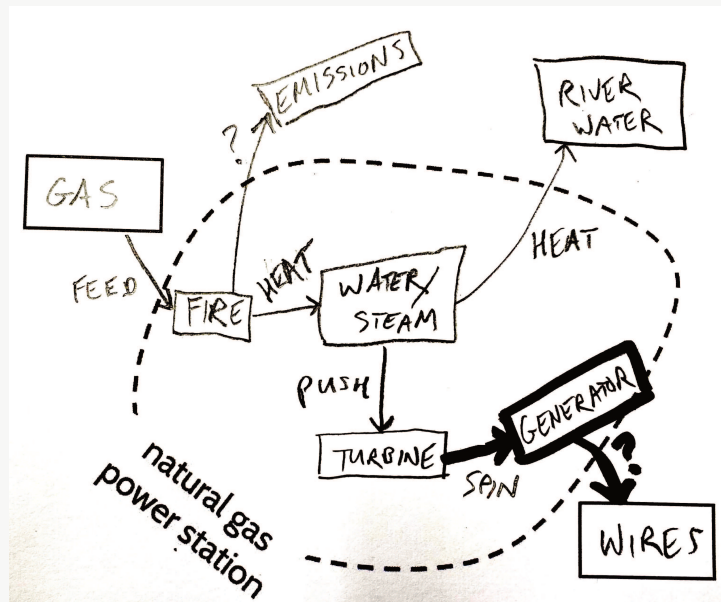
If students begin to trace matter instead of energy (e.g., the natural gas goes into the boiler, and then into the stack through emissions), redirect them with probing questions, such as: *What do these orange arrows show? What do the blue arrows show? Is that the path of energy transfer from the gas to the wires?*

Use the third question on **slide E** to help students distinguish between energy transfer and matter transfer. Ask, *How are matter changes related to energy changes? Is energy transfer the same as matter transfer? What is one example in the gas plant where they are different?*

Building toward: 5.A.1 **Develop a model based on evidence to illustrate the energy and matter changes** in a generator, including **energy transfer through contact between moving parts and energy transfer at a distance through fields**. (SEP: 2.3, DCI: PS3.A.2; CCC: 5.2)

Model the natural gas power plant as a class. Bring the class back together to go step by step, asking students to share how they modeled the natural gas power plant as you sketch a class model on a blank sheet of chart paper. Be sure to space out the components in your diagram to allow room for labeling energy transfer arrows with action words.

The completed diagram may look something like the image below. Listen for some agreement on valid verbs for the main transfers of energy within the system. If students have questions about any specific transfers, identify them with a question mark. As with the wind diagram, the question mark from generator to wires is essential--again, one primary goal is to discover that we don't know how the generator works.



ADDITIONAL GUIDANCE

Students may be confused about how to describe the energy transfer process arrow for natural gas heating up. Push them to draw on their knowledge from chemistry to describe the process in terms of particle motion. Say, *Heating up describes our experience of what is happening. But what do the particles of natural gas actually do when they heat up?*

3 · MOTIVATE A CLOSER LOOK AT THE GENERATOR

15 min

MATERIALS: Dissecting a Generator, science notebook, chart paper, markers

Observe that both power plants have a generator. Present **slide F**. Ask students to turn and talk about the questions on the slide:

1. *What do these power plants have in common?*
2. *What questions do we still have about how these power plants produce electrical energy?*

Have students share their ideas with the whole class. Listen for them to point out that both power plants end with the production of electrical energy in power lines, and that before this, there is something called a generator that spins. Listen for ideas and questions about how this happens.

Say, *I actually have a couple of generators right here.* Produce the 2 mini dissecting generators.

Motivate the transition to LED bulbs. Say, *In Lesson 2, we read a little bit about different kinds of light bulbs. The bulbs we used in Lesson 2 were incandescent bulbs. But many of the lights installed in modern buildings are LED bulbs, because they use less energy to create the same amount of light. In other words, they're more efficient. They're also much safer, because they don't get hot enough to burn you if you accidentally touch them.*

ADDITIONAL GUIDANCE

It is important that you use the right bulbs for the battery in Lesson 2 and for the generator in this lesson. The batteries are 1.5 volt and cannot always light up LEDs, which is why we recommend 1.2-1.5 bulbs for those. An incandescent bulb is more forgiving and will still be powered below the recommended voltage. But an LED will not work below its voltage threshold; it works better with the hand-powered generators, which will produce adequate voltage if spun quickly. These generators can light up incandescent bulbs, but it is much more difficult to do.

Demonstrate the generators with an LED, and draw attention to the snap. Attach a super-bright red LED bulb (2V, 20 mA) using alligator clips to 1 blue and 1 yellow wire to show students that they work, and then show how to pull them apart. As they click back together, draw attention to the magnet by saying, *Wow, they really snapped back together quickly, did you hear that snapping noise? See whether you can figure out what is pulling them back together so quickly when I pass them around.*

Pass around the dissecting generators. Present **slide G**. Pass the generators around the room, and ask students to record noticings and wonderings in their notebooks. After everyone has had a chance to examine a generator, ask students to help you list its parts. Record their ideas on a blank sheet of chart paper or on the board. Make sure you have recorded at least the first two of the following (the wire and the magnet) before moving on:

- coils of wire (or coils of "copper wire")
- a magnet or magnetic strip
- a shaft, axle, rod, or something else that describes a turning mechanism
- insulated wires
- a case

ADDITIONAL GUIDANCE

If students didn't notice the magnet, make sure they do now by saying, *Did anybody figure out what was making it click together so quickly? Could this black rim around the inside be responsible for that?*

4 · NAVIGATE: EXIT TICKET

5 min

MATERIALS: 8.5 x 11 paper



Navigate by motivating reverse engineering the generator. Distribute a sheet of paper to each student. Ask them to put their name on the paper and respond to the prompts on **slide H** as an exit ticket:

1. *How do you think the parts we identified in the generator might work together to transfer energy to wires?*
2. *What would we need to do to re-create this phenomenon using these basic parts?*
3. *How could this help us understand the energy crisis in Texas in 2021?*

Collect students' exit tickets as they leave class. *

* SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

If your students have experience with a speaker unit or another technology that uses solenoids, consider giving them a chance here to make connections between similar types of systems. Ask, *Have you seen these same parts working together in another type of system?*

End of day 1

MATERIALS: None

Navigate with a Turn and Talk about the exit ticket responses. Present slide I and return students' exit tickets. Give students a moment to turn and talk about what they wrote. Suggest that if they have any new ideas, they can tell their partner about those as well.

After 2 minutes, if students had ideas for creating a generator, say something like:

- *You all seemed very optimistic that we could re-create this, and I agree.*

If most students responded that it could not be done, say something like:

- *Most of you seemed doubtful that we could make our own generators, but I have some ideas.*

Introduce supplies and take a quick poll. Say, *I have some materials very similar to those we identified in the generators during our last class. I have some wire wrapped around a tube, and some magnets, and a nail that we can use as a shaft. Show of hands, how many people think this is going to work?*

Define criteria for success. Present slide J and say, *What should we define as our criteria for success? How will we know whether our generators are successful?* Listen for responses such as:

- It should light a bulb or an LED.
- It should light up the power strip city we made earlier.
- If it can light more bulbs, then that means it's more successful.
- If it can light bulbs for longer, then that means it's more successful.

Write the class's agreed-upon criteria on the board, a whiteboard, or chart paper.

Students may also offer generator criteria such as, "It should charge our phones." If so, say, *That sounds pretty ambitious. Let's start simpler and then see where we can get.* Students should **not** connect any generators to their phones, as they could damage the internal electronics.

SAFETY PRECAUTIONS



Powerful magnets like those recommended for use here can snap together and pinch fingers. Tell students to keep the magnets far apart when not in use, and consider providing gloves to prevent pinched fingers. Keep magnets at least 20 cm away from sensitive electronic and data storage devices.

Students should **not** connect any generators to their phones or other devices. A high-quality generator can certainly damage internal electronics.

6 · BUILD A GENERATOR

27 min

MATERIALS: Building a Generator

Build the generators. Present **slide K**. Break students into groups of 3-5 to build generators. Distribute the materials for the Building a Generator lab to each group, and safety goggles.

If your power strip city is set up, consider giving students an opportunity to rewire it with LED lights. Though they may have a hard time lighting the whole city, they should be able to light two LEDs connected to one power strip.

Distribute a copy of *Generator Engineering Task* to each student. Instruct them to follow its procedures with their group and to write down their answers to its questions. The handout is organized as a series of four Design Challenges:

- Design Challenge 1: Magnet Arrangement
- Design Challenge 2: Rotation Speed
- Design Challenge 3: Sturdy Magnets
- Design Challenge 4: Wire Wraps Constraint

If some groups spend most of their time on Design Challenges 1 and 2, that's OK. Design Challenge 1 is the most important for understanding that how the magnets **change** inside the coil is what generates electrical energy. Some groups, on the other hand, will likely finish Design Challenges 1 and 2 rather quickly and be eager to move on to making their generator work even better.



Move around the classroom with the dissecting generator and ask probing questions to make sure that students are making connections between what they are doing and our questions about how generators work.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students identify **design criteria relevant to the generator's performance, transferring motion energy to light** (i.e., lighting multiple bulbs, lighting a bulb for an extended time). (SEP: 3.6, DCI: PS3.A.2)
- Students **evaluate their own design against the agreed-upon criteria** as they **build and test their generator design**. (SEP: 3.6, CCC: 4.1)
- Students **use the Design Challenges on the handout to improve their designs in real life**. (SEP: 3.6)
- Students describe **a relationship between a specific design variable (magnet spinning speed, magnet position, number of wire coils) and the energy output** (e.g., "If we spin the nail faster, the light is brighter"). (SEP: 3.6)

What to do:

- As students discuss design criteria, encourage them to decide on criteria that can be scaled up and improved. Instead of simply agreeing to the criterion "light a bulb," push students toward "light as many bulbs as we can" or "light a bulb for as long as we can."
- As students work through the Design Challenges on the handout, move from table to table and clarify which specific point in the generator design they are focusing on. Ask, *Which part of the generator are you focusing on right now?* Expect responses such as: the position of the magnets, keeping the magnets moving for more time, the number of wire coils.
- As students build and test their generator, ask them to explain why they constructed it in a particular way. Use probing questions to help them clarify their thinking about energy for each challenge, such as:
 - *Based on your testing so far, how would the generator work differently if you change the speed of the moving magnets? How might that affect the energy output of the generator?*
 - *How does the output of the generator change when the magnets get knocked out of place? How might that affect the efficiency of the generator?*
 - *What about if you wrapped half as much wire? A quarter as much wire?*

Building toward: 5.B Design and build a generator system to transfer motion energy to light that meets agreed-upon criteria, manipulating variables and collecting data to identify failure points and improve performance. (SEP: 3.6, DCI: PS3.A.2; CCC: 4.1)

Clean up and come back together. When there is about 10 minutes left of class, ask students to clean up their areas, and then bring the class back together to debrief.

7 · DEBRIEF THE GENERATOR INVESTIGATION

10 min

MATERIALS: *Generator Engineering Task*

Debrief the investigation. Present **slide L** and elicit responses to the questions on the slide, as shown in the table below.

Suggested prompt	Sample student response
<i>What happened when you tried to use your generator to power one LED?</i>	We could do it! We got some flashes, and if we wrapped string around the nail, we could get it to light up for longer. (Expect some groups to have had more success at this than others.) When the magnets were facing the same poles outward, the generator didn't work at all.
<i>More than one LED?</i>	We couldn't do it. We could do two easily, but we had trouble lighting up three or four. We could do it, but we had to use string to spin the nail faster.
<i>What factors seem to affect the energy output of the generator?</i>	Position of the magnets. Speed of the nail. How many coils are wrapped around the tube.
<i>What might cause energy loss to the surroundings?</i>	There's probably some friction between the nail and the tube. The faster it goes, the more energy is lost to the surroundings, probably because it rubs more.

8 · NAVIGATE: EXIT TICKET WITH A PARTNER

3 min

MATERIALS: None

Assign an exit ticket to do in pairs. Close out the discussion about the generators and navigate into day 3 with the exit ticket on **slide M**. The exit ticket introduces new ideas, so have students do the work in partners to complete one exit ticket each at the bottom of the back of *Generator Engineering Task*.

Collect the exit tickets as students leave class. If students are unclear on the difference between energy transfer through direct contact and energy transfer at a distance, plan to review this briefly at the start of their next class period.

End of day 2

9 · NAVIGATE

3 min

MATERIALS: None

Make connections to magnets and energy transfer at a distance. Present **slide N**. Tell students to turn and talk with a partner about the prompts on the slide:

1. *Why did we want to know more about how energy transfers between the magnet and the coil of wire?*
2. *How do we know these parts are transferring energy?*
3. *What do we know about magnets that might help us figure this out?*

Give students a minute before asking them to share out. Listen for responses such as:

- We want to look at the magnets and the wire more closely, because they were transferring energy without touching.
- We know there is energy transfer because when we spin the magnet, energy gets to the light bulb and lights it up, so the energy must go through the wire.
- Magnets can move things without touching.

If students don't bring up fields themselves, don't bring it up. The term *field* will be defined later in this lesson. If students do bring it up, validate this idea, and then continue to reference the space around the magnet until the end of the lesson so students who do not know what a field is have the opportunity to construct a conceptual understanding.

10 · REVISIT COMMUNITY AGREEMENTS: “RESPECTFUL” CATEGORY

5 min

MATERIALS: Community Agreements poster (from Lesson 1)

Revisit the “Respectful” category of our Community Agreements. Point to the “Respectful” category of the poster and present **slide O**. Say, *There were a lot of creative ideas on how to get our generators working in the last class. I saw lots of groups respectfully sharing equipment and ideas.*

Then ask students to consider and respond to the prompts on the slide:

- *Why is it important to be respectful when working together on an engineering problem?*
- *Which agreements in the “Respectful” category were important for making that work successful?*
- *Which agreements should we work on?*

Listen for responses such as:

- Give others time to work with the equipment and share ideas.
- Provide others with support and encouragement.
- Critique ideas by testing them, don't just dismiss them.

ALTERNATE ACTIVITY

If there is time, consider asking students to gather around the Community Agreements poster and use sticky dots or check marks to indicate which agreements they think we should prioritize.

11 · BUILD UNDERSTANDING ABOUT MAGNETISM

20 min

MATERIALS: Compass Experiments and Demonstrations, chart paper, markers

Consider energy transfer at a distance. Present **slide P**, and arrange students into groups of 3-5 at their tables. Distribute a compass to each table and read the text on the slide: *A compass is a tool that can move when it is near a magnet.* Then read the prompts:

- *How do you think energy is transferring through systems when the compass moves? How do you know?*
- *How could we use compasses to determine how magnetic energy transfers?*

Elicit student ideas. Students who have just finished the OpenSciEd Chemistry course may have some ideas about fields and subatomic particles. Listen for students to suggest:

- Energy transfers through something invisible, like a field. Students might use the phrase “magnetic fields,” or they may say something else like “magnetic forces,” “magnetism,” “energy fields,” “force fields,” or “magnetic pulls.”
- Energy jumps in order to transfer, like static electricity, or lighting.

Accept all these ideas. Highlight that whatever is happening between the magnet and the coil, we think it’s invisible, because we don’t see anything happening.

Use the compass to investigate the space around our generators. Present **slide Q**. Distribute the generators students built previously. Read the prompts on the slide:

- Use a compass to look for changes in the space near your generator when it is not spinning. What do you notice?*
- Look for changes near the generator when you spin the generator, both slowly and quickly. What do you notice?*
- Use a compass to investigate the space around a magnet. What patterns do you notice in how the compass points?*

Instruct students to use their materials to follow these prompts in order. `

Once students have completed prompts A and B, encourage them to remove a magnet from their generator and use the compass to investigate the space around this magnet to address prompt C.

Organize our results as a class. Bring the class back together and present **slide R**. Prepare a piece of chart paper as a T-chart to keep track of our observations. On the left side, write “What we tried,” and on the right side, write “What we saw.” Enlist students’ help in making the chart with their observations so far, with one student volunteer writing on the poster and another volunteer calling on peers.

Students may add the following to the T-chart poster:

- “The compass near a generator” under *What we tried* and “The compass changes direction when the generator spins” under *What we saw*.
- “The compass near a generator spinning fast” under *What we tried* and “The compass changes direction more when the generator spins faster” under *What we saw*.
- “The compass near a magnet” and “The compass points in different directions at different places near the magnet.”

Motivate investigations as a class with all the compasses. Ask students whether anybody tried moving their compass around. Ask, *What could we do to tell what the direction of the compass would be at various locations around the generator at the same time?* Listen for ideas about using more than one compass.

Conduct investigations A-C with all the compasses as a class. Gather all students around a table; ask them to bring their compasses and put them on the table. Present **slide S**. Follow the steps below to do further demonstrations.

Read the question of investigation A aloud, from **slide S**: *How do the compasses point if no magnets are nearby?* Keep the compasses at least 6 inches from each other, so they do not interact and affect each other. It is possible for a compass to get reversed. If you notice a compass pointing differently than the other compasses, remove it from the table.

Have students record these results. They may add the following to the T-chart poster:

- *What we tried:* "No magnets nearby"
- *What we saw:* "Compasses all point the same direction"

Investigation B: *Do all the compasses change in the same way when we spin our homemade generator? Hold a homemade generator close to the compasses and spin it slowly. The compasses will change direction as the magnets inside the generator move.*

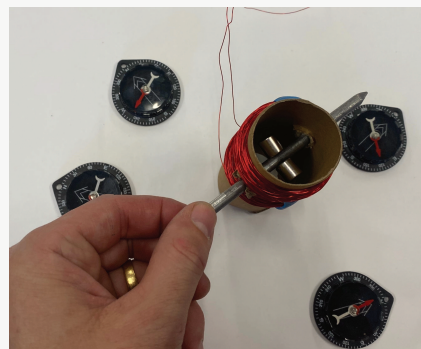
Have students record these results. They may add the following to the T-chart poster:

- *What we tried:* "Many magnets near the slowly spinning generator"
- *What we saw:* "Compasses all change direction as the generator spins"

Investigation C: *We have a generator that can supply much more electrical energy. Measure changes in the space around the generator again when you crank this high-output generator. What do you notice? Hold the high-output generator close to the compasses and spin it slowly. The compasses will change direction slightly if you are spinning the generator slowly enough and if it is close enough to the compasses.*

Have students record these results. They may add the following to the T-chart poster:

- *What we tried:* "Compasses near a high-output generator"
- *What we saw:* "Compasses change direction, but not as much"



Turn and talk about energy transfer at a distance. Present slide T. Ask students to turn and talk about the prompts on the slide with a partner they don't usually sit with.

After the Turn and Talk, call on students to share their ideas, as in the table below.

Suggested prompt	Sample student response
How far out in space do you think the magnet is able to transfer energy? How do you know?	Not very far, because the compasses have to be close. It could be really far, because the whole Earth is magnetic. The energy probably gets weaker as it gets farther away, because the compasses respond more when they are closer.
Is the energy that transfers through the coil of wire magnetic, electrical, or both? Why do you think that?	It's magnetic, because it's making the compasses move. It's electrical, because electricity travels through the wires to light up a bulb. Magnetism doesn't travel through wires.
How could we investigate this?	We could put the compasses near a coil of wire. We could connect our coil to an energy source and use the compasses to investigate. We could try making an electromagnet.

ADDITIONAL GUIDANCE	Students may not yet understand the distinction between electrical and magnetic energy, and that's fine. Try not to distinguish these as fundamentally different forms of energy. Instead, encourage students to focus on "magnetic changes" versus "electric changes." For example, "electrical energy" can light up a bulb, whereas "magnetic energy" can make a compass move.
---------------------	--

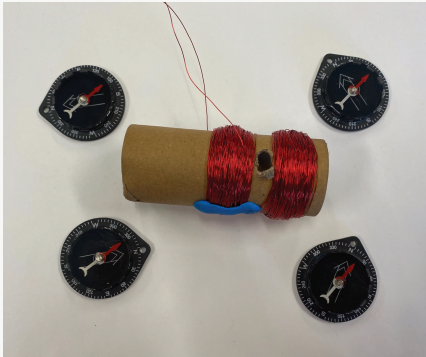
Conduct investigations D-E together as a class. Present slide U.

Read the directions for *Investigation D: Use compasses to measure the magnetism near a coil with no magnets nearby, not connected to anything.* Remove the nail and magnets from a generator, so it's just a tube with wire wrapped around it. Arrange the compasses so they all point in the same direction, then place the coil of wire among the compasses. Ask students what they notice. The compasses should not be affected at all.

Have students record these results. They may add the following to the T-chart poster:

- *What we tried:* "Compasses near a coil of wire with no magnets"
- *What we saw:* "Compasses aren't affected at all"

Read the directions for *Investigation E: Connect the coil to the high-output generator, at least 3 feet away from the coil and the compasses.* Connect the high-output generator to the coil, using 2-4 alligator clips to extend the distance from the generator to the coil. Ask students what they notice. Students should be convinced that any effect on the compasses is from the coil itself, not from the high-output generator. Crank the generator back and forth to see the compasses



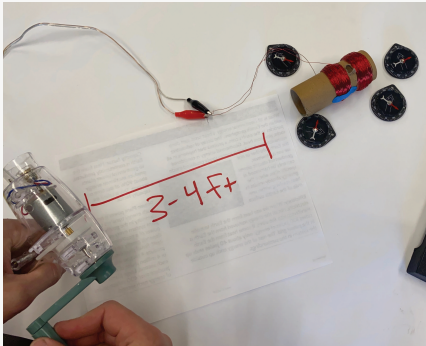
change direction back and forth. Cranking the generator steadily in one direction might cause a pattern similar to what they saw with the magnet, but this conclusion isn't essential.

Have students record these results. They may add the following to the T-chart poster:

- *What we tried:* "Compasses near a coil of wire with an energy source"
- *What we saw:* "Compasses change direction when energy transfers to the coil"

Turn and talk about energy transfer at a distance. Present slide V. Because students are already out of their regular seats, encourage them to find another partner they don't usually sit with for this Turn and Talk.

After the Turn and Talk, call on students to share their ideas, as in the table below.



Suggested prompt	Sample student response
<i>Is the energy that transfers through the coil of wire magnetic, electrical, or both? Why do you think that?</i>	The coil can cause electric changes, like lighting a light bulb. It can also cause magnetic changes, like moving a compass. If the coil is connected to a light, the wires can transfer energy to that light, but it can also cause compasses to move.
<i>How does this help us understand how energy is transferring into our devices through the wire?</i>	The generator has to transfer energy that's in the moving magnets to electrical energy in the wire. This experiment helps us understand that the generator is able to change magnetic energy to electrical energy--the coil can affect both.

Build understanding about fields. Present slide W. Ask a student to read the text on the slide aloud, and give the class a moment to read it silently: *Scientists call the space around a magnet where energy can transfer a magnetic field. When energy transfers into or out of the field, the field changes its strength and shape.* This is an opportunity for students to add the term *field* to their Personal Glossary.

Then discuss the prompts on the slide as a class. Additional prompts are suggested below to push the conversation further and draw out some of the key ideas from the lesson.

Suggested prompt	Sample student response
<i>What matter changes have we seen today that could be evidence of changing fields?</i>	The compasses are made of matter, and they move in response to changes in fields. We used compasses moving as evidence of changing fields, but the fields would have been changing even if the compasses weren't there.

Suggested prompt	Sample student response
<i>How can evidence of changing fields help us explain energy transfer from the generator?</i>	The generator only works when the magnets are moving or changing. Moving magnets changes the field. Maybe a changing field causes electricity?
<i>Where do we think that the fields are actually changing? Just near the coil, or everywhere along the wire?</i>	All the wires carry electricity. The coil has a lot of wire in one place, but it's still just carrying electricity. If the coil of wire is creating fields, then it would make sense, if the wire is changing fields, to transfer energy everywhere along the wire.
<i>How does this help us explain why we need to get something spinning in order to generate electricity in the wire?</i>	By moving the magnets, we can change the fields, which can generate electricity.
<i>Does it matter whether we move the magnets and keep the wire still, or whether we move the wire and keep the magnets still? How do we know?</i>	It doesn't matter, because when we dissected the generator, we moved the wires, and in our homemade generators, we moved the magnets.
KEY IDEAS Listen for the following key ideas: • Motion of a magnet can generate changing fields, which can cause energy transfer at a distance (and vice-versa). • When moving matter (e.g., pushing wind or steam) moves the magnets inside a generator, that can cause energy transfer into wires through changing fields.	

12 · MODEL ENERGY TRANSFER IN THE GENERATOR

10 min

MATERIALS: 8.5 x 11 paper, chart paper, markers, whiteboard and dry erase markers (alternate)



Make connections between matter changes, energy transfer, and fields. Present **slide X**, and direct students to return to their table to work in groups of 3-5 to consider the prompts on the slide:

- *Can we track how matter changes or moves within the system?*
- *What does matter tell us about how energy transfers?*
- *How can matter changes (or movement) tell us about energy transfer through fields?*

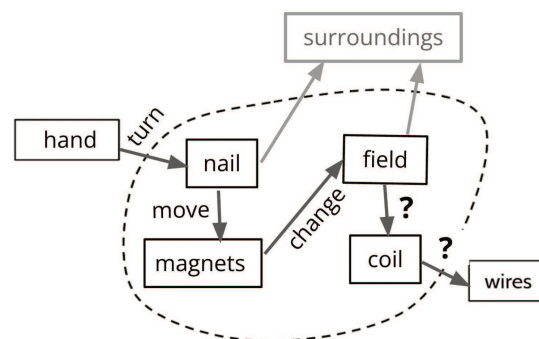
Distribute a half-sheet of blank paper to each student. Encourage them to begin sketching an energy transfer diagram to help them think through the prompts, using the key components on the diagram of the generator as a starting point. Circulate around the room, encouraging students to include fields as a component in their model.

Alternatively, students can respond to the prompts with written sentences, or even by talking through their answers out loud. If they do not draw a model, clarify that we'll use these ideas to build an energy transfer model as a class.

Model energy transfer in the generator. Present **slide Y**. Call on students to build an energy transfer model of the generator as a class on chart paper or a whiteboard. Key components of this model include: nail, magnets, field, coil, and wires.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: As a class, students should model something like this:



- Students should again use our box and arrow conventions, and label the arrows with at least one action word to describe energy transfer. (SEP: 2.3)
- The class model should include energy transfer to a field with the arrow labeled as “change” (i.e., magnets change the field). (DCI: PS3.A.3; CCC: 5.2)
- Students will likely not yet have a clear idea of how energy transfer manifests in the wires. This uncertainty will motivate the investigations in Lesson 6. Rather than pushing students to figure this out now, encourage them to highlight this limitation of their model by putting a question mark on that arrow. (DCI: PS3.A.2)

What to do:

- If students have trouble getting started, direct them to the key components in the diagram of the generator. Write these components with arrows between them, leaving enough space to label each arrow with a verb to describe the interaction that transfers energy.
- If students have trouble suggesting verbs to describe energy transfer through contact of moving matter, ask, *How would you describe what the [hand, nail] is doing to the [nail, magnets]?*
- If students have trouble suggesting a verb to describe energy transfer at a distance through the field, ask, *How did the compasses respond when the magnets moved? What does this mean for the field? What do the magnets do to the field?*
- Don't force students to include the surroundings in their model, as we have no direct evidence that energy is lost to the surroundings here. If they want to point out that energy is lost as the nail rubs against the tube, the interaction can be labeled “heats up” or “rubs against”.

Building toward: 5.A.2 Develop a model based on evidence to illustrate the energy and matter changes in a generator, including energy transfer through contact between moving parts, and transfer at a distance through fields. (SEP: 2.3, DCI: PS3.A.2, PS3.A.3; CCC: 5.2)

ALTERNATE ACTIVITY

This modeling task can be assigned in groups or partners, or even as an individual assessment. If that is done, make sure the class gets a chance to quickly come to consensus at some point about what the model should look like.

13 · DISCUSS MATTER-ENERGY CONNECTION AND ADD TO THE PROGRESS TRACKER

5 min

MATERIALS: None

Make it explicit that changes in matter and transfer of energy tend to occur together. Present slide Z. Ask:

- *Based on the models we made over the past few days, how are matter changes related to energy transfer?*
- *Is there a cause-effect relationship?*

Listen for responses such as:

- Matter changes and energy changes often happened together.
- Energy transfer can cause a change in matter, or vice-versa.
- Energy and matter aren't exactly the same thing, but they're definitely related.

Clarify that matter doesn't always take the same path that energy does. *

Add to Progress Trackers. Give students a few minutes to add their ideas to their *Progress Trackers*.

* SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

We have begun to consider the interplay between matter and energy, but the wires don't obviously fit the pattern we've seen so far. Even though students should recognize the energy transfer from the generator to the wires, they may not identify that matter is changing inside the wires as well. If they have questions about this, note those as excellent questions or lines of inquiry, but try to shift focus to the visible parts of the generator itself. In Lesson 6, students will explore energy transfer at the particle level, and the pieces will fit together.

14 · NAVIGATE: EXIT TICKET

2 min

MATERIALS: 8.5 x 11 paper



Navigate with an exit ticket. Distribute a sheet of paper to each student and present **slide AA**. Ask them to put their name on the paper and respond to the prompts on the slide as an exit ticket:

- *Why do some power plants need to get something spinning in order to transfer electrical energy to the wires?*
- *What parts of our generator energy transfer model support this idea?*
- *What questions do you still have about energy transferring through the wire?*

Collect these exit tickets as students leave class.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students should say that **the motion of magnets causes field changes**, resulting in the **transfer of energy**. (DCI: PS3.A.3; CCC: 5.2)
- Students should **identify parts on their model** where **the magnets move** and where **the field changes, generating electrical energy**. (SEP: 2.3, PS3.A.3; CCC: 5.2)
- Students should have questions about what is happening in the wire when energy transfers through it. We haven't yet introduced electrons, but students who have taken chemistry or physics may mention electrons or electric current as a place to go next.

What to do: The reading in Lesson 6 goes more deeply into the role of fields, but students may not get much out of the reading initially if they haven't yet grasped the basics. Use this exit ticket to gauge how ready students are for the reading. If most answers show little grasp of fields, plan to do a close reading of the home learning in the next class period. If most answers show some basic understanding of fields, you may be able to skip some steps of the close reading.

Students will make their own models on a transfer task assessment in a few class periods, so use this exit ticket as a formative assessment to indicate how much practice they might need in preparation.

Building toward: 5.A.3 **Develop a model based on evidence to illustrate the energy and matter changes** in a generator, including **energy transfer through contact between moving parts, and transfer at a distance through fields**. (SEP: 2.3, DCI: PS3.A.3; CCC: 5.2)

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

A Common Core ELA standard is targeted in this lesson from the category of **Key Ideas and Details**.

- **CCSS.ELA-Literacy.RST.11-12.3.** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

Students will follow a multistep procedure to test the effect of the configuration of the magnets and the rate of rotation of a generator on the transfer of energy in a wire. They use their results to consider the constraints for building a generator.

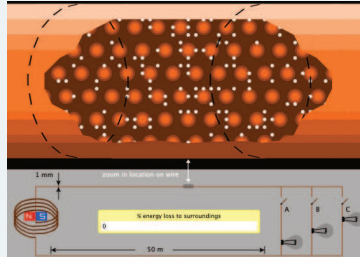
LESSON 6: How does energy transfer in wires?

PREVIOUS LESSON We used diagrams of power plants to figure out how they transfer energy into wires, which made us wonder what is happening inside generators. We dissected a generator, then built our own, and used compasses to investigate fields. Lastly, we modeled energy transfer through fields inside our generators, and made connections between matter and energy to refer to as we move forward.

THIS LESSON

INVESTIGATION

3 days



Wilensky, U. 1999. NetLogo.
<http://ccl.northwestern.edu/netlogo/>.
 Center for Connected Learning and
 Computer-Based Modeling,
 Northwestern University. Evanston, IL.

We read about fields to help us model energy transfer more closely, focusing on transfers inside a wire. Using a simulation, we explore how characteristics of an electrical system could influence the transfer of electrical energy, and check our results using classroom equipment. We then refine our Engineering Design Trackers with ideas from the simulation.

NEXT LESSON We will develop a model showing how insufficient supply entering the electrical system could lead to buildings losing power during a crisis. We will test our models using *Electric City*, and we will notice that to keep the lights on in one building, we need to cut power to others. We will use data to test for correlations with county-level factors, and we will consider limitations on this analysis.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
 HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
 HS-ETS1-4



WHAT STUDENTS WILL DO

6.A Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about motions of particles or energy stored in fields. (SEP: 8.2; DCI: PS3.A.3; CCC: 2.2)

6.B Use a simulation to model electron flow inside a wire in order to identify patterns, answer questions, and determine relationships between independent and dependent variables involving electrical energy transfer that can be interpreted to reengineer and improve the electric grid. (SEP: 1.3; DCI: PS3.A.4; CCC: 1.3)

Transfer Task 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. (SEP: 2.3, 6.5; DCI: PS3.A.2, PS3.A.3, PS3.D.1; CCC: 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Electric and magnetic fields change when energy transfers into or out of them.
- Electric fields can push electrons. “Electrical energy” is the energy of the movement of electrons transferring through pushes from fields.
- A turbine transfers energy through electric and magnetic fields to the electrons in a wire, causing them to slosh back and forth continuously.
- Electrons cause the atoms of the wire material to heat up, transferring energy from the system to the surroundings as “heat”.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Navigate into the lesson by connecting to the Lesson 5 exit ticket.	A	<i>Changing Fields</i>
2	15 min		DO A CLOSE READING ABOUT FIELDS Have the class read a summary of how electric and magnetic fields affect particle motion inside a wire. Guide them to identify and define important words, then identify evidence and answer two questions.	B-C	<i>Changing Fields</i>
3	12 min		MODEL ENERGY TRANSFER IN THE FIELDS READING Have partners choose a passage from the reading and model it using energy transfer diagrams. Give each pair a rubric to evaluate another pair's model and revise their own.	D-E	8.5 x 11 paper, <i>Changing Fields</i> , <i>Rubric for Modeling</i>
4	5 min		MODEL THE TRANSFER OF MATTER INSIDE A WIRE Have partners sketch a model that reflects how matter transfers inside a wire.	F	8.5 x 11 paper, <i>Changing Fields</i>
5	5 min		IDENTIFY MODEL LIMITATIONS AND NEW QUESTIONS Have students and partners mark limitations in their new models and write down any new questions.	G	8.5 x 11 paper
6	5 min		NAVIGATE: ASSIGN HOME LEARNING Give a home learning assignment that compares two models of electrons to prepare students for the simulation investigation in the next class period.	H	<i>Models of Electrons</i>
<i>End of day 1</i>					
7	3 min		NAVIGATE Discuss two questions that lead the class toward closer investigation of what is happening inside a wire when it's connected to an energy source.	I-J	<i>Models of Electrons</i>
8	10 min		INTRODUCE THE COMPUTER SIMULATION Use the handout to introduce the simulation and discuss the variables that can be manipulated or measured, as well as the causes and consequences of energy loss in the system. Demonstrate real-life energy loss and current measurement.	K-L	Inside Wire Simulation Investigations
9	12 min		CONDUCT AN INVESTIGATION USING THE SIMULATION Have students follow the handout to choose independent and dependent variables, investigate them using the simulation, and record conclusions about the relationships uncovered.	M	Inside Wire Simulation Investigations
10	5 min		SHARE CONCLUSIONS Have the groups share conclusions from their wire simulation investigations.	N	chart paper for Wire Sim Results poster, chart paper markers
11	10 min		CARRY OUT REAL-LIFE EXPERIMENTS Conduct simple classroom experiments to demonstrate that the results of the computer simulation match up with real-world results.	O	Real-Life Wire Investigations

Part	Duration		Summary	Slide	Materials
12	5 min		NAVIGATE: EXIT TICKET Complete an exit ticket to connect the results of our investigations to larger themes.	P	8.5 x 11 paper, Wire Sim Results poster
<i>End of day 2</i>					
13	3 min		NAVIGATE Navigate by connecting the results of our investigations to our larger work.	Q	Wire Sim Results poster
14	8 min		FILL IN THE ENGINEERING DESIGN TRACKER Add to the <i>Engineering Design Tracker</i> to include the main ideas on the Wire Sim Results poster.	R	<i>Engineering Design Tracker</i> (from Lesson 3), Wire Sim Results poster
15	30 min		ASSIGN THE MOTOR TRANSFER TASK Introduce the assessment context and review assessment resources.	S-T	<i>Motors Transfer Task</i> , hand-crank DC generator, 1.5 volt D battery, alligator clips
16	2 min		REVISIT “MOVING OUR SCIENCE THINKING FORWARD” Reflect on what we have done to move our science thinking forward since the beginning of the unit.	U	Community Agreements: Moving our science thinking forward
17	2 min		NAVIGATE: EXIT TICKET Complete an exit ticket to consider whether it's time to put the pieces together to explain how insufficient supply affected communities in Texas.	V	8.5 x 11 paper
<i>End of day 3</i>					

Lesson 6 • Materials List

	per student	per group	per class
Inside Wire Simulation Investigations materials	• <i>Wire Simulation Investigation</i>	• computer	• 1.5 volt D battery • coil of wire with the ends sanded • tape • ammeter • sandpaper
Real-Life Wire Investigations materials			• 1.5 volt D battery • power strip • ammeter • alligator clips • incandescent light bulbs • hot plate OR cup of ice • wire of various lengths (like the tubes with wrapped wire from the homemade generators in Lesson 5) OR extra alligator clips
Lesson materials	• science notebook • <i>Changing Fields</i> • 8.5 x 11 paper • <i>Models of Electrons</i> • <i>Engineering Design Tracker</i> (from Lesson 3) • <i>Motors Transfer Task</i>	• 8.5 x 11 paper • <i>Changing Fields</i> • <i>Rubric for Modeling</i>	• chart paper for Wire Sim Results poster • chart paper markers • Wire Sim Results poster • hand-crank DC generator • 1.5 volt D battery • alligator clips • Community Agreements: Moving our science thinking forward

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Prepare a piece of chart paper for the Wire Sim Results poster students will make on day 2.

Test this simulation link for the lesson: <https://www.openscienced.org/general/acdc/>

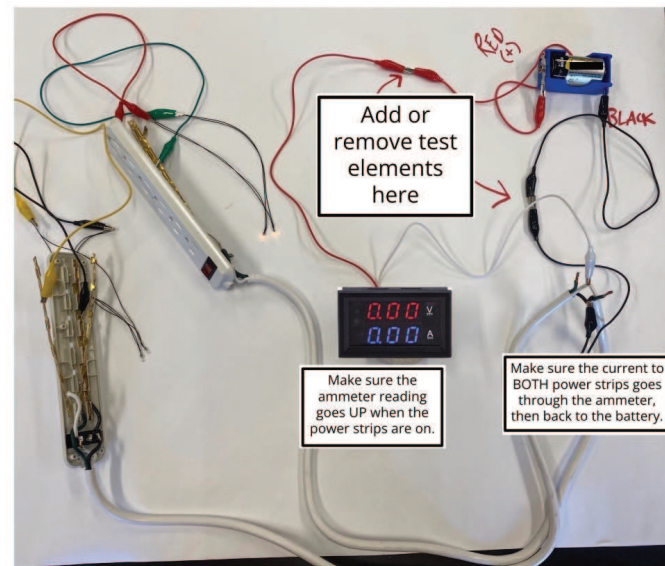
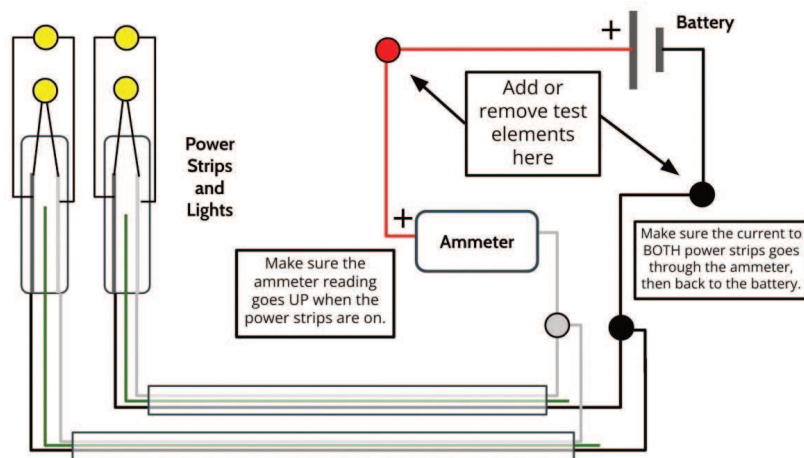
Battery and Wire Demonstration (day 2):

- 1.5 volt D battery
- coil of wire with the ends sanded
- tape

Real-Life Wire Investigations (day 2): Set up these materials as described in *Real-Life Investigations Prep*

- digital ammeter
- alligator clips
- wire of various lengths (like the tubes with wrapped wire from the homemade generators in Lesson 5) OR extra alligator clips

- hot plate and mug of water OR mug of ice



If you have an ammeter or a good-quality multimeter, you can use it in these investigations. Otherwise, refer to *Ammeter Construction Directions* for instructions on how to build your own. The video https://www.youtube.com/watch?v=F_vvuk_GjIU&list=PLSLDxqPb5NQmKp9RwUjcb82h4QO6x4G_&index=9 also shows how to build a digital ammeter.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

In previous lessons, students have explored at a macroscopic level how electrical energy is generated and how it transfers within a system. In this lesson, they shift focus to energy transfer at the level of particles and fields, using readings and a simulation. In particular, they generate data to explore factors that affect energy loss and/or current through a wire, and connect their conclusions to what happened in Texas in 2021. Thus, this lesson contributes to students' understanding that the scale at which a problem is investigated can help us identify additional causes of the problem.

In the reading, students model energy transfer involving fields, and then they incorporate the concepts of energy transfer involving changing fields into their larger energy model. In the simulation, students see firsthand how “electrical energy” connects to the motion of electrons in a wire, and how the temperature of a material connects to the motion of the atoms of that material.

In the optional *Algebra in Circuits* (and accompanying optional **slide W**), students get more firsthand experience with concepts of voltage and an algebraic relationship related to circuits, such as Ohm's Law and an operational definition of resistance.

Students encounter or co-develop definitions for the following words in this lesson: *electron, current, field*. **Do not** post any words on the Word Wall until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Similar to previous lessons, we intentionally avoid using the term “forces”, as students can use the vocabulary of “pushes” and “pulls” to explain how energy transfers.

Unless they complete the extension, most students will not be solving equations that involve voltage or current, as the focus is on the core concepts of energy transfer and energy loss. The materials included here were designed to help students understand voltage, current, and power at a conceptual level. Students do not practice algebraic relationships involving resistance or make calculations involving parallel circuits.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

3 min

MATERIALS: science notebook, *Changing Fields*

Connect to the Lesson 5 exit ticket. Present slide A. Ask 2-3 students to share their ideas about the first prompt: *Why do many power plants need to get something spinning in order to transfer electrical energy to the wires?* Listen for suggestions that the movement can change the magnetic fields, which somehow influences the electricity.

Say, *What parts of our generator energy model support this idea? What don't we understand yet?* Listen for students to say that the only energy transfer “at a distance” was between the magnets and the coil, and that we saw the compasses changing, so we know the field was changing. If students have more questions than answers, that’s OK.

Introduce the reading. Say, *There’s still a lot we don’t understand about what’s happening in the wires, or how the fields make energy transfer without touching possible. I have a reading with details about fields and wires that I think will clear up some of our questions.* Distribute *Changing Fields* to each student.

2 · DO A CLOSE READING ABOUT FIELDS

15 min

MATERIALS: *Changing Fields*

Explain and begin the close reading. Present slide B. Say, *This reading has a lot of important ideas in it, but it’s also very dense, so it can be hard to understand everything at first. We’re going to do a “close reading,” which means we will read through it several times, each time with a different goal. This first time, our goal is to circle words that seem very important, whether they are familiar or unfamiliar. After we read through the first page, we will decide which words we can already define, and which words we have more questions about.*

Have all students follow along with reading the first page while students take turns reading it aloud. You can call on students randomly *, or ask them to call on each other every few sentences (sometimes referred to as “popcorn”). Then, ask students what they circled. Expect them to identify words that appear frequently (magnetic field, electric field) as well as important words that may be less familiar (particle, electron, nucleus, electric current). Encourage students to use context clues to come up with our own definitions of some of these terms, as shown in the table below.

* ATTENDING TO EQUITY

Use explicit strategies to keep students engaged while reading: Use a strategy for calling on students to read that will keep all students engaged. For example, you can write students’ names on tongue depressors or popsicle sticks, and pick a name stick randomly to choose the next person to read a few sentences.

Suggested prompt	Sample student response
<i>What is one word that we can already define?</i>	Field.
<i>How would you define the word “field” as it’s used in this reading?</i>	A magnetic field is something that can make a compass change direction, but we didn’t talk about electric fields.
<i>How does the reading refer to electric fields? What does it say these fields do?</i>	It says, “Electric fields push charged particles”, so I guess that could be our definition.
<i>What is another word that seems important?</i>	“Electron”, but we haven’t talked about those.

Suggested prompt	Sample student response
Can we use context clues from the reading to figure out what an electron is?	It says that atoms have electrons in them, which are negatively charged, and when they flow together they make an electric current.
How can we put those ideas together?	Electrons are negatively charged particles in atoms that can flow together in an electric current.

Reread page 1, identifying evidence and answering questions. Present slide C. Say, *Now read the same page again, but this time, underline any evidence that connects to things we've seen in class. Then, answer the slide's two questions, writing in the margins of your reading.*

Circulate around the room and positively narrate what you see in students' work. For example, say, *I see (name) underlining evidence that connects to what we've seen. I see (name) answering the first question in the margin.*

Read page 2, identifying evidence. After 2-4 minutes, say, *If you feel done with the first page and the questions, move on to read page 2. Page 2 is a little more advanced, but it still connects to things we've seen in class, so you can keep underlining useful evidence.*

Share answers to the two questions. Look for most or all students to have underlined some passages and answered both questions. Ask a few of those students to share quick answers to both questions, as follows:

- *What happens when a magnetic field changes?* It causes a change in the electric field.
- *How does this affect charged particles in a wire?* Electric fields can push charged particles, so this can cause electrons to flow.

3 · MODEL ENERGY TRANSFER IN THE FIELDS READING

12 min

MATERIALS: 8.5 x 11 paper, *Changing Fields*, *Rubric for Modeling*



Choose a bolded passage in partners, then model it on a blank sheet of paper. Show slide D. The choices on page 1 are called “medium”; those on page 2 are slightly tougher, so they're called “spicy”. Ask students to find a partner; distribute a blank sheet of paper to each pair.

Give students 1 minute to choose a passage, then show slide E. Remind them of the conventions we've used for energy transfer models, and tell them their models should relate to fields in some way, so “field” should be a component in their diagrams.

Circulate around the room and look at students' work to ensure that they are practicing our diagram conventions. Arrows should not be used to “point things out”; instead, arrows should show energy transfer from one component to another. Students can label an arrow pointing into a field component as “change”, to show that changing the field transfers energy into that field.

Use a rubric to evaluate another pair's model. When a pair of students finishes their model, ask them to trade work with another pair whose model is finished. Give each pair a copy of *Rubric for Modeling* and instruct them to use it to evaluate the other pair's work. When both pairs have gone through the rubric, they should talk through and revise their own models, then prepare to hand them in at the end of class.

Add to Progress Trackers. Before collecting students' models, ask students to copy them over the model into their Progress Trackers.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Fields store and transfer energy. In their energy transfer diagram, students should label energy transfer arrows into a field with the word “change” or the like. Energy transfer arrows from a field to a particle (electron) should be labeled “push” or the like. (DCI: PS3.A.3)
- Students should connect passages from the reading to evidence from class or personal experience, including: electrical energy transfers in wires, changing magnetic fields can generate electricity, a buildup of electrical energy can cause a spark, and so forth. We can incorporate information from the reading with our own evidence to model energy transfer in wires. (SEP: 8.2; DCI: PS3.A.3)
- Students can use particle-scale mechanisms for interactions between particles and fields to identify cause-effect relationships for larger systems like a wire, and explain evidence of energy transfer we’ve seen in class, such as compasses moving and wires heating up. (DCI: PS3.A.3; CCC: 2.2)

What to do: If students are deeply struggling as they attempt to model passages from the reading, try to coach them with useful ideas. For example, say, *What does the reading say is happening to the field? What action word does the reading use?* If their models don’t make perfect sense, that’s OK, as some confusion will be cleared up in the partner conversation while using the rubric. However, it will be helpful to ensure that all students have clearly labeled the passage they are modeling.

If students are ready, encourage them to try modeling a “spicy” bold passage from page 2 of the reading.

Building toward: 6.A.1 Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about motions of particles or energy stored in fields. (SEP: 8.2; DCI: PS3.A.3; CCC: 2.2)

4 · MODEL THE TRANSFER OF MATTER INSIDE A WIRE

5 min

MATERIALS: 8.5 x 11 paper, *Changing Fields*

Model what is happening in a wire. Say, *Scientists often use multiple models to understand a phenomenon through multiple lenses. Our energy transfer models tell us a lot about where the energy comes from and where it goes. But we still have a lot of questions about how that energy transfer is happening inside the wire. How is matter changing to make energy transfer possible?*

Present **slide F**. Read the prompts on the slide aloud:

- *Imagine you could zoom into the wire to “see” what is happening inside of it when it is connected to a generator.*
- *What do we think happens to the matter in the wire that could explain how fields cause energy transfer?*
- *On the back of your partner model from the reading, draw a model that shows matter changes that you might “see” inside a wire as energy transfers.*

Give students 3–4 minutes to sketch a model on the back of their previous model of what is going on in a wire as energy transfers into it and through it. These models will help to identify shared understandings and gaps that create the need to explore, at a different scale, how electrical energy transfers within a system.

5 · IDENTIFY MODEL LIMITATIONS AND NEW QUESTIONS

5 min

MATERIALS: 8.5 x 11 paper

Stop and jot about model limitations and new questions. Show slide G. Ask students (still in partners) to draw question marks near the parts of their model where they would like to know more or where they think the model has limitations. Then ask them to write down any new questions that the new model raised for them and their partner about what is happening inside the wire.



Have partners write both names on their sheet with the two models and the questions so you can collect it as an exit ticket at the end of class.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Look for students to integrate ideas from the reading into their responses, for example: (SEP: 8.2)

- Fields are invisible. It's possible to represent them visually in a model, but students may choose to leave them out. (DCI: PS3.A.3)
- Particles such as electrons are too tiny to be seen with light, but they can still be modeled visually. Students' models should show some cause-effect mechanism for why a wire transferring electrical energy is different from a wire that is not transferring energy. (DCI: PS3.A.3; CCC: 2.2)
- Particle-scale mechanisms for interactions between particles and fields can be used to identify cause-effect relationships for larger systems like a wire, and to explain evidence of energy transfer we've seen in class, such as compasses moving and wires heating up. (DCI: PS3.A.3; CCC: 2.2)

What to do: Don't spend too much time or effort coaching students on their model; instead, use it as a formative assessment to check their understanding of particle interactions. If students are not used to thinking at a particle scale, you will see this in their drawing. In that case, it may be important to spend more time on this concept at the beginning of the next class period.

- The reading contains many clues that can be used to visualize what is happening inside a wire. Encourage students to refer to phrases in the reading as a reference when making their model, such as:
 - Pg 1. "Atoms have a positively charged *nucleus* in the center and negatively charged particles called *electrons* at certain distances out from that center."
 - Pg 1. "In copper atoms, the pull on the outer electrons is pretty weak, and electrons can pass from atom to atom. This means that electrons can move through copper wherever they are pushed. Electric fields push charged particles, so changing the electric field inside a copper wire can cause a flow of electrons."
 - Pg 2. "If nearby electrons have a place to go (like the ground or the other end of a battery), they will flow in the direction they are pushed"
 - Pg 2. "These electrons collide with copper particles as they move, causing those copper particles to move faster. We feel these faster atoms as an increase in temperature."

Note: These passages are not all the same as the bold passages that students used in their previous modeling exercise. These passages connect to matter, while the other passages connect to energy. (Some passages connect to both matter and energy.)

Building toward: 6.A.2 Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about the motions of particles or the energy stored in fields. (SEP: 8.2; DCI: PS3.A.3; CCC: 2.2)

6 · NAVIGATE: ASSIGN HOME LEARNING

5 min

MATERIALS: *Models of Electrons*



Introduce the home learning. Present **slide H**. Distribute *Models of Electrons*. Students should use the reading to guide them through evaluating two models of electrons, using evidence we have collected in class and in the reading *Changing Fields*. Say, *This home learning will set us up to go deeper with our modeling of what is happening inside wires. This will give us more clues for how to think about what happened with energy transfer during the Texas blackouts.*

Collect the exit ticket as students leave class.

End of day 1

7 · NAVIGATE

3 min

MATERIALS: *Models of Electrons*

Turn and talk. Present **slide I** and have students turn and talk about the first two questions. They should have questions about how matter transfers inside the wire, and how this contributes to energy transfer. They should note that the home learning discussed the smallest particles of matter, and that because we can't see these particles directly, we need to model how they might behave to see whether the predictions match our evidence.

Share out briefly about connections to Texas. Keeping in mind that you want to leave plenty of time to work with the simulation, ask 1-2 pairs to share out around the third question on the slide. Students may suggest that electrical current froze, like water in a pipe freezes, or that voltage could have somehow dropped, or that the current stopped flowing. Accept all ideas.

Navigate to using a computer simulation. Show **slide J**. Read the first part of the slide aloud, then elicit responses to the prompts. Say, *What variables would we want to manipulate in a computer simulation to help answer some of our questions? What would we want to see?* Accept all responses, but listen for students to mention that the particles in a wire are too small to see, and that a simulation allows us to change things and immediately see how that affects the factors we're interested in.

8 · INTRODUCE THE COMPUTER SIMULATION

10 min

MATERIALS: Inside Wire Simulation Investigations

Orient to the simulation, answering handout questions Questions 1-3. Show **slide K**. Arrange students into partners and distribute *Wire Simulation Investigation* to each student. Point out that the image on the screen will help them see which part of the simulation to focus on for each question on the handout. Ask them to begin the simulation by clicking “Setup” and “Go/Pause”.

Circulate around the room as students think through and answer Questions 1-3. Students should make a connection between the speed of the electrons and the measurement on the ammeter showing “current” through the wire in mA. Check for understanding verbally by asking, *What factors about the wire seem to connect to the number on the ammeter near the battery?*

Discuss connections between the simulation and a real wire. Once most students have completed Questions 1-3, draw the class’s attention to **slide L**. First, quickly review what the measurements in the simulation actually mean. Say, *What does the “energy loss to the surroundings” percentage tell us? What do the “ammeters” measure?* Probe students until it’s clear that class has a clear understanding of these ideas.

Listen for suggestions such as:

- Energy loss to the surroundings is how energy doesn’t go to the light.
- Energy loss to the surroundings tells us how much heat is lost.
- The ammeter measures how much electricity is in the wire.
- The ammeter measures how fast the electrons are moving.

Say, *We know this simulation is a model, and a model is only useful if its predictions actually match results in real life. What evidence could help us figure out whether these mechanisms in the simulation are true in the real world?*

Listen for suggestions such as:

- We could connect a real ammeter in the same way it’s connected in the sim, and see how it behaves.
- We could connect a wire to a battery and see whether it heats up. This would mean it’s losing energy.

Demonstrate energy loss through a wire. Temporarily tape the sanded ends of a coil of wire to a 1.5 volt D battery and invite a volunteer to come up and feel it, or carry it around the classroom so everyone can feel the wire heat up. If the wire gets too hot, disconnect it.

SAFETY PRECAUTIONS

The wire should heat up very quickly. Allow students to feel the wire, but do not pass it around without supervision, as it could get hot enough to burn someone or even light something on fire.



Suggest doing similar investigations with real equipment later in class to check the conclusions students reach. Point out that you have a real ammeter in the room, and suggest that the class check the conclusions they reach with real equipment later in class. Say, *For now, use the simulation to reach what conclusions you can. Then we’ll check those conclusions with a real ammeter and real wire.*

9 · CONDUCT AN INVESTIGATION USING THE SIMULATION

12 min

MATERIALS: Inside Wire Simulation Investigations



Select independent and dependent variables to investigate. Show slide **M** and instruct students that their next task is to carry out an investigation in the simulation. Say, *Now that we're pretty convinced that the simulation model makes valid predictions, let's use it to answer some of our deeper questions with a proper scientific investigation. Choose an independent variable and a dependent variable that could help us learn more about what happened in Texas, or about how to reengineer and improve our electric grid.* Instruct them to follow Questions 4-5 on the handout to select and record their group's variables. **

State a research question and investigate it with the simulation. Tell students to work through Questions 6-11 to identify a research question, and then conduct an investigation to answer this question. *

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Use *Simulation Investigation Key* as guidance.
- Question 4: Good dependent variables are **electric current (measured by the ammeter) or % energy loss to surroundings.** (DCI: PS3.A.4)
- Question 5: Good independent variables are wire length, wire width, temperature.
- Question 6: **Research questions should include the IV and DV from Question 5 and 4.** (SEP: 1.3)
- Question 8: Likely results:
 - **Increasing the wire length and/or decreasing the wire width results in less energy transfer and more energy loss.**
 - **Lower wire temperatures result in slightly more energy transfer and slightly less energy loss, but the effect is small.** (SEP: 1.3; DCI: PS3.A.4)

What to do: Students will have different levels of familiarity with independent, dependent, and controlled variables. As you circulate among the tables, look at answers to Q4-Q6. If groups have moved on to Q7 before you've seen their research question, ask to see it to confirm that it is valid.

If students haven't chosen electric current (measured by the ammeter) or % energy loss to surroundings for Q4, say, *The dependent variable should be something that could depend on another variable. What is a value that the simulation calculates that you can't simply choose a value for yourself?* (SEP: 1.3)

If students haven't chosen wire length, wire width, or temperature for Q5, say, *The independent variable should be something that you choose, and that you can change directly. What is something in the simulation that you can choose to change?* (SEP: 1.3)

If students obtain a result that doesn't seem right, **ask them which variables they held constant as controlled variables** (Q7). Ask them to show you one example of how they collected data, and look for inconsistencies with their research question that could explain their odd result. (SEP: 1.3)

Building toward: 6.B.1 Use a simulation to model **electron flow inside a wire** in order to **identify patterns, answer questions, and determine relationships between independent and dependent variables** involving **electrical energy transfer** that can be interpreted to reengineer and improve the electric grid. (SEP: 1.3; DCI: PS3.A.4; CCC: 1.3:)

* SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

Help students (1) recognize the cause-effect relationship between changing the characteristics of the wire (cause) and the percentage of energy loss of the system (effect) and (2) consider the mechanisms at the particle level that explain this.

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

If students select variables that can't be measured quantitatively, coach them toward different variables. An experiment involving non-quantitative variables (such as wire material) can be valid, but it's more challenging to see a pattern. Contrast "As wire length/width increases..." against "As wire material increases..." Without numbers we can't identify a relationship.

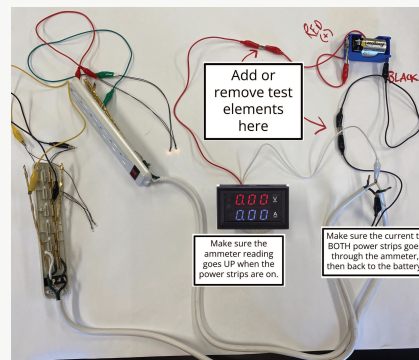
* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Students may notice that the wire's temperature doesn't increase as energy lost to surroundings increases. Acknowledge this, and say, *Like all models, this model has limitations. I recommend that we use the values given in the simulation for now - we can check it with real wires later to see if the computer model holds up.*

Look at students' answers to Question 9, and prepare to demonstrate real-life experiments. As groups complete their investigations, some will have ideas about Question 9. You will have already prepared some equipment that will allow your class to investigate these same relationships with real equipment. If students struggle to come up with ideas for experiments, remind them of the ammeter that you pointed out earlier. Ask, *How could we use our real ammeter to investigate a relationship that's similar to what you looked at in the simulation? If current measured by this ammeter is a dependent variable, what could we choose to change as our independent variable?*

Due to the limited time allotted, set up the materials in advance so the maximum time possible is spent carrying out experiments rather than troubleshooting connections. See *Real-Life Investigations Prep* for details on how to prepare the demonstration.

Notice that the setup allows turning at least two circuits on and off, as well as adding or removing test elements as independent variables. (see activity 11 - CARRY OUT REAL-LIFE EXPERIMENTS)



10 · SHARE CONCLUSIONS

5 min

MATERIALS: chart paper for Wire Sim Results poster, chart paper markers

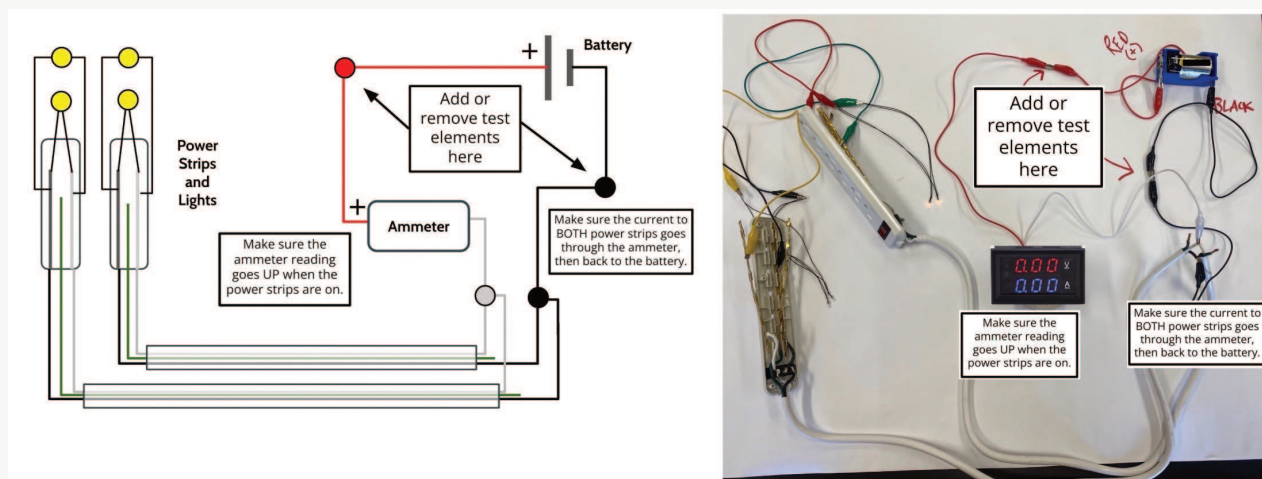
Create a public record of results. Present **slide N** and prepare a piece of chart paper as shown on the slide. As students complete their handouts, direct a representative from each group to the chart paper to write their response to Q8. Groups who worked more quickly likely made more progress with Q11 and could have uncovered relationships that no one else saw. Where possible, encourage groups who uncovered a unique result to share that result on the chart paper, to avoid redundancy. This has the added benefit of ensuring that even the groups who worked more slowly will feel that their contributions are valued.

11 · CARRY OUT REAL-LIFE EXPERIMENTS

10 min

MATERIALS: Real-Life Wire Investigations

Demonstrate conclusions with real equipment. As mentioned above, due to the limited time allotted, you will want to set up the materials in advance so the maximum time possible is spent carrying out experiments rather than troubleshooting connections. A successful demonstration will clarify that the conclusions reached in the simulation connect to the real world. See *Real-Life Investigations Prep* for details on how to prepare the demonstration.



Notice that the setup allows turning at least two circuits on and off, to see the effect on the total current through the battery. Before adding or removing test elements as independent variables, point out the effect that turning on more bulbs has on the total current measured by the ammeter.

Follow students' lead--prioritize experiments they suggest themselves.

 **Carry out experiments using real equipment to verify simulation results.** Display slide O. As you discuss the results of your class's real-life experiments, ask questions to help students make connections to the particle models they made on the previous day.

To show the effect of wire length on current, use two coils of wire from the generator experiment with different numbers of wire wraps (100 and 400, for example). Students will see the current decrease for longer wires.

To show the effect of temperature, use a coil of wire on a hot plate, or another source of heat or cold available in your classroom, such as a cup of ice. Though students may have concluded that "*As wire temperature increases, electric current decreases*" in the simulation, this effect is tiny in real life. Guide students to the understanding that tiny changes are usually less important than obvious ones.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Flipping a switch on the power strip changes the electric field inside the wire. Electrons move inside the wire, pushed by the electric field. This causes energy to transfer to devices like the light bulb. (DCI: PS3.A.3; CCC: 2.2)
- Electrons collide with atoms of the wire, which causes the wire to heat up. (DCI: PS3.A.3; CCC: 2.2)
- A longer wire means more particle collisions with wire atoms, which means more energy loss. (DCI: PS3.A.3)
- Changing the temperature of the wire atoms doesn't change current much, because the electrons are only loosely attracted to those atoms. (DCI: PS3.A.3)

What to do: Whenever you uncover a result with these real-life experiments, take the opportunity to connect it to the particle-scale model students made the previous day, and the energy transfer models of passages from *Rubric for Modeling*. (SEP: 8.2) The simulation visuals should have made some things clearer, and this whole-class conversation is a chance to check those connections.

If students have trouble articulating how these results connect to the particle model, ask questions to connect to particles in the simulation. Say, *What particles are the electrons interacting with as they move? Why might increasing the length of the wire decrease how quickly electrons flow through that wire?*

Building toward: 6.A.3 Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about motions of particles or energy stored in fields. (SEP: 8.2; DCI: PS3.A.3; CCC: 2.2)

12 · NAVIGATE: EXIT TICKET

5 min

MATERIALS: 8.5 x 11 paper, Wire Sim Results poster

Reground students in our larger line of inquiry. Relate the results to what happened in Texas and how to reengineer and improve our electric grid. Show **slide P** and point out the two questions at the top; instruct students **not** to answer these questions on their exit ticket! They are only for reference in thinking through the question at the bottom of the slide.

Distribute a sheet of paper to each student, and direct their attention to the poster. Say, *Choose a result from our Wire Sim Results poster. Write it on your exit ticket, and then write your answer to the bulleted question on the slide: Is the result you chose more connected to question A or B? What is the connection?* Collect students' exit tickets as they leave class.

End of day 2

13 · NAVIGATE

3 min

MATERIALS: Wire Sim Results poster

Connect our simulation results to our larger engineering task. Show slide Q. Ask students to name a result that connects to the larger task of reengineering and improving our electric grid. As they share ideas, ask the class to connect this result to a specific detail about that task.

Listen for responses such as:

- As wire width increases, energy loss decreases. So, we should use thicker wires in our grid.
- As wire length increases, energy loss increases. So, we should keep our wires as short as possible to prevent energy loss. This also means that sources of energy like solar cells or power plants should be built next to the buildings that use this energy.
- As wire temperature increases, energy loss increases a little bit but mostly stays the same. This means we could, in theory, lose less energy by making the wires cold, but this probably isn't worth it.

14 · FILL IN THE ENGINEERING DESIGN TRACKER

8 min

MATERIALS: science notebook, *Engineering Design Tracker* (from Lesson 3), Wire Sim Results poster



Use the Wire Sim Results poster to add to the *Engineering Design Tracker*. Present slide R and have students get out their own *Engineering Design Trackers*. Tell them to use the ideas on the Wire Sim Results poster to fill in another row of the tracker, and remind them that some of the new ideas are more relevant to engineering solutions than others. Rather than simply choosing the conclusion they reached with their group, encourage them to choose a conclusion that clearly connects to reengineering and improving our grid.

Students' entries may look something like this. If time is limited, it's better for students to go deeply into one new science idea to think through applications and constraints (the third and fourth columns) rather than simply listing more science ideas (the second column).

Lesson #	What are the new science ideas we figured out that could make the systems in our community more reliable?	How could engineers designing a power grid for a community apply these ideas in practice?	What constraints might make it hard for engineers to apply these ideas?
6	Energy is lost over a wire. A thicker or shorter wire means less energy loss. The cold doesn't affect energy loss very much.	They could use really thick wire. They should also not let the wires get too hot if possible, maybe by using less insulation. They should also build power plants as close to the community as possible.	Having less insulation could be dangerous. Also, thick wire is probably more expensive, and building power plants closer means building more of them, which could be way more expensive, and could annoy people in the neighborhoods where the plants would be built. Also, maybe the resources that the plants need aren't close to the community, like water, wind, or coal.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

Students should connect one or more conclusions from the Wire Sim Results poster to an idea that will help us reengineer the grid.

- Longer wire means more energy loss, less electric current → Power plants should be built closer to the communities they serve, so wires can be shorter. (SEP: 1.3; DCI: PS3.A.4; CCC: 1.3)
- Larger-diameter wire means less energy loss, more electric current → Large-diameter wires should be used instead of smaller wires. (SEP: 1.3; DCI: PS3.A.4; CCC: 1.3)
- Lower/higher wire temperature means about the same energy transfer, about the same energy loss. → It's unlikely that cold temperature affects wires much--if anything, more energy will flow in the cold. (SEP: 1.3; DCI: PS3.A.4; CCC: 1.3)
- These choices have trade-offs and constraints--energy sources such as coal plants can be unhealthy for residents, and thicker wire costs more money. (CCC: 1.3)

What to do: Circulate around the room and browse students' answers to the second column of the *Engineering Design Tracker*. If they have trouble getting started, point to the poster and say, *Those relationships we uncovered are new science ideas, even though they don't have a specific name. Which of those relationships could help us reengineer and improve our electric grid to lose less energy or to increase electric current to our buildings?*

If students have identified a useful idea/relationship but have trouble applying this idea in column 3, ask specific questions that help make the connection. For example, *I like that you're focusing on the width of the wire. What type of wire would you recommend we use in our electric grid?* Or, *I like that you're focusing on wire length. What would this mean about where we'd want to build our power plants, to keep wires as short as possible?*

If students struggle to think through constraints, make a counter-argument to what they wrote in column 4. For example, say, *What might make it hard for a city to choose to use thicker wire?* Or, *Why might we not want to build, say, a coal or nuclear power plant right next to people's homes?*

Building toward: 6.B.2 Use a simulation to model electron flow inside a wire in order to identify patterns, answer questions, and determine relationships between independent and dependent variables involving electrical energy transfer that can be interpreted to reengineer and improve the electric grid. (SEP: 1.3; DCI: PS3.A.4; CCC: 1.3)

15 · ASSIGN THE MOTOR TRANSFER TASK

30 min

MATERIALS: science notebook, *Motors Transfer Task*, hand-crank DC generator, 1.5 volt D battery, alligator clips

Provide context for the assessment. Say, *When we transfer kinetic energy into a system that uses magnets and a coil of wire to generate electricity by turning something in the system, we call the system a generator. In a generator, magnets transfer energy from motion into changing magnetic fields, and the energy then transfers to changing electric fields. These electric fields cause electrons to move and transfer electrical energy along the wire. Therefore, one way to think about a generator is as a device that transforms kinetic energy (motion) into electrical energy.*

Present **slide S** and pose the question as a Turn and Talk: *If you input kinetic energy to a generator, the output is electrical energy. What do you predict would happen if we input electrical energy to the system instead? Imagine you attached a generator like we used in class to a source of electrical energy (like a battery or another generator), and turned on the source so energy was transferring into the generator.*

After 1-2 minutes, elicit a few ideas. Students may say kinetic energy would come out and the crank would spin, or the wires would heat up. Accept all ideas without judgment.

Connect a high-output generator (**not** a homemade generator!) to a 1.5 volt D battery. Connect two alligator clips to the hand-crank generator, and connect it to either another generator or a battery. Allow students to observe the crank moving on its own.



Distribute the assessment. Explain that students will have the opportunity to explore this phenomenon in an assessment. Distribute *Motors Transfer Task* to each student.

Mention available resources. Display **slide T**. Remind students that they can use their science notebook, data, *Progress Tracker*, and *Progress Tracker*, from Lessons 1-5 as resources for understanding as they complete this assessment. Give them the remainder of the class period to work on the task. *

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: See the *Motors Transfer Task Key*.

What to do: Use the key to evaluate students' work. If a student scores low, consider giving them a chance to discuss the assessment with you and then take the other version, *Transformer Transfer Task*, which assesses the same 3-D elements in a different context. Refer to the *Motors Transfer Task Key* for ideas on how to score this similar student work.

This assessment is not building toward a lesson-level performance expectation. It is designed to assess a performance expectation from the NGSS, below.

Transfer Task 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. (SEP: 2.3, 6.5; DCI: PS3.A.2, PS3.A.3, PS3.D.1; CCC: 5.2)

Collect all assessments before students leave. Determine a time for students to finish the assessment if they did not have enough time in class.

* ATTENDING TO EQUITY

Universal Design for Learning: On this assessment some students may benefit from using alternative modalities to express their thinking for any or all of the questions. Consider allowing some students to verbally explain their answers while you record their thinking on paper, or allowing some students to use gestures, images, or manipulatives to support their explanations. Especially early in the unit, encouraging students to use multiple modalities to show their thinking builds their skills, and creates equitable pathways for all students to demonstrate proficiency throughout the unit.

16 · REVISIT “MOVING OUR SCIENCE THINKING FORWARD”

2 min

MATERIALS: Community Agreements: Moving our science thinking forward

Reflect on what we have done to move our science thinking forward. Show **slide U**. Call students' attention to previous thinking about Community Agreements related to “Moving our science thinking forward”. Say, *Many of you have clearly mastered the ideas in this transfer task. Some of you are still working through them, and that's OK. Let's reflect for a moment on how we got there. Do you think you could have shown mastery on this transfer task before we began this unit? Who is coming up with the key ideas?*

Encourage students to be honest. If they don't think that they've made much progress, this is a time to say so. If they believe that the teacher is usually the one coming up with the key ideas, this may be a chance for you to reflect on what opportunities students have to own this learning themselves.

If assessment at your school offers students multiple attempts at mastery, emphasize the third question. Say, *If you haven't shown mastery yet, what can you do next to change that? What are some resources you can use to master energy transfer models, and energy transfer through particles and fields?* A key resource here is *Changing Fields*--students should practice making energy models of a few phrases from the reading. If they can connect this thinking to their design thinking about the generator, they will be far more successful on *Motors Transfer Task*.

17 · NAVIGATE: EXIT TICKET

2 min

MATERIALS: 8.5 x 11 paper, science notebook

Connect back to Texas and navigate into the next lesson with an exit ticket. Present **slide V** and distribute a sheet of paper to each student. Ask them to respond to the prompt as an exit ticket: *Do we have all the pieces we need to model how insufficient supply could have affected energy transfer into certain communities in Texas when temperatures dropped during the storm?*

Collect the exit tickets to refer to in Lesson 7.

Additional Lesson 6 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

A Common Core ELA standard is targeted in this lesson from the category of **Craft and Structure**.

- **CCSS.ELA-Literacy.RST.11-12.4.** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

Students identify the main ideas from a reading about charged particles to determine the model that better reflects the interactions between electrons in a wire.

LESSON 7: What could have caused the disparities we saw in the blackouts in Texas?

PREVIOUS LESSON We read about fields to help us model energy transfer more closely, focusing on transfers inside a wire. Using a simulation, we explored how characteristics of an electrical system could influence the transfer of electrical energy, and checked our results using classroom equipment. We then refined our Engineering Design Trackers with ideas from the simulation.

THIS LESSON

PROBLEMATIZING

2 days



Jared Tennant

We develop a model based on evidence from previous lessons showing how insufficient supply entering the electrical system could have led to reduced energy transfer into certain communities in Texas when the temperatures dropped in February 2021, resulting in buildings losing power. We test our models using Electric City, and we notice that to keep the lights on in one building (the “hospital”), we need to manually cut power to others. We wonder about how the power company in Texas made decisions about who lost power, and we use data to test for correlations with county-level factors that might have impacted decision-making. We consider limitations on this analysis to motivate seeking information about patterns at a smaller grain size.

NEXT LESSON We will listen to a podcast featuring a scientist whose research group used satellite data to investigate patterns in who lost power in Texas. We will read about two fictionalized families in Texas and consider how existing disparities can make the impact of a power outage inequitable across communities. We will consider battery power as a potential solution.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

7.A Develop a model showing how insufficient supply entering the system could lead to reduced energy transfer into certain communities in Texas when the temperatures dropped, resulting in buildings losing power. (SEP: 2.3; DCI: PS3.B.4; CCC: 5.2, 5.3)

7.B Develop and test a correlational hypothesis to investigate tradeoffs inherent in making decisions about energy, and then consider limitations on this analysis to motivate seeking information about patterns at a smaller grain size. (SEP: 1.6, 4.2, 4.3; DCI: ETS1.B.1; CCC: 2.1, 3.3)

WHAT STUDENTS WILL FIGURE OUT

- Power companies in Texas probably had to make decisions about who lost power in some places in order to keep providing power in others.
- There is no one factor that explains why some counties in Texas lost power and others did not.
- There are limitations associated with analyzing data grouped into counties, because the scale of a county is large.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Navigate into the work by deciding to put the pieces together. Brainstorm what to include in a model to show how an insufficient supply could have affected energy transfer into certain communities in Texas when the temperatures dropped.	A	
2	10 min		MODEL IN GROUPS Have student groups model energy transfer to show how insufficient supply could have affected energy transfer into certain communities in Texas when the temperatures dropped.	B	sheet of three-hole-punched paper, <i>Progress Tracker</i>
3	10 min		CREATE A CONSENSUS MODEL Create a consensus model. Highlight what we do not know about how limited supply is distributed during a crisis. Motivate using Electric City to test our ideas.	C-D	chart paper, markers
4	15 min		USE ELECTRIC CITY TO TEST OUR IDEAS Use Electric City to model an energy supply crisis. Orient students to the ammeter. Make decisions to keep the lights on in the “hospital”.	E	Electric City Decisions Demonstration
5	5 min		NAVIGATE BY CONSIDERING OUR DECISION-MAKING Have students turn and talk about human decision-making. Make it clear that students’ concerns about ethics and decision-making have a rightful presence in the science classroom.	F	
<i>End of day 1</i>					
6	5 min		NAVIGATE WITH A STOP AND JOT Have students stop and jot about human decision-making.	G	
7	15 min		ANALYZING DATA AS A CLASS Lead the class in discussing a hypothesis and making a prediction. Orient to CODAP and run a correlation analysis between hospitals and percent out. Have students turn and talk about what might vary between counties.	H-J	poster of questions from slide I (optional), computer or device with access to https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FbDWoSkKcv8T1sfwwgGva%2Ffile.json
8	15 min		ANALYZE DATA IN SMALL GROUPS Have student groups complete <i>Texas County Data Analysis</i> to develop a hypothesis, test it using CODAP, and consider limitations on the scale of our analysis.	K	Looking for Correlations
9	5 min		DISCUSS LIMITATIONS OF THE DATA SET Motivate a better look at counties by discussing the limitations of our analysis. Use a Turn and Talk to get students thinking about patterns within a county.	L-P	<i>Texas County Data Analysis</i>

Part	Duration		Summary	Slide	Materials
10	5 min		NAVIGATE Have students update their <i>Progress Tracker</i> . Navigate into Lesson 8 by forecasting an interview with an expert. Have students make predictions about how data reported at a smaller scale might yield different results.	Q-R	<i>Progress Tracker</i>

End of day 2

Lesson 7 • Materials List

	per student	per group	per class
Electric City Decisions Demonstration materials			• hand-crank DC generator (not homemade) • 8-12 alligator clips • 3 dissected power strips • 6-7 incandescent bulbs (not LEDs) • 300mA ammeter (or multimeter set to an ammeter setting scaled to meet the bulbs you are using) • paper tents for labeling city parts
Looking for Correlations materials	• <i>Texas County Data Analysis</i>	• computer or device with access to https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FbDWoSkKcv8T1sfwwgGva%2Ffile.json	
Lesson materials	• science notebook • sheet of three-hole-punched paper • <i>Progress Tracker</i> • <i>Texas County Data Analysis</i>		• chart paper • markers • poster of questions from slide I (optional) • computer or device with access to https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FbDWoSkKcv8T1sfwwgGva%2Ffile.json

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

You will create a consensus model in this class on day 1. Prepare this poster ahead of time by titling a piece of chart paper "Consensus Model for Energy Transfer During the Crisis".

To make it easier to see the questions we are considering while also projecting CODAP together, prepare a poster ahead of time with the questions from **slide I**:

- *Is there a correlation between the 2 variables we chose to look at?*
- *What conclusions can we make about our hypothesis from this analysis?*
- *Does this analysis tell us anything about what caused the crisis?*

Alternatively, you can skip this and flip back and forth between projecting CODAP and **slide I**.

The data in CODAP was retrieved from <https://www.dshs.texas.gov/chs/hosp/Hosplis2021.pdf> and census.gov. You can modify or add data to the CODAP dataset using the integrated tools.

SAFETY PRECAUTIONS

1. Wear sanitized safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of the demo preparation.
2. Use caution when using sharp (tools, wires, etc.), which can cut or puncture skin.
3. Keep away from water sources to prevent shock when working with electrical circuits or electricity sources.
4. If the battery or wires overheat, disconnect the circuit to prevent skin burns or fire.
5. Do not use lithium-ion batteries - they are a fire hazard!
6. If the battery is leaking or has residue on it, do not use it.
7. Use caution when working with glass bulbs. If a bulb shatters, the pieces of glassware are sharp and can cut hands.
8. Make sure all materials and equipment are returned to the appropriate location upon completing activities.
9. Wash your hands with soap and water immediately after completing this activity.

Day 1: Electric City Decisions Demonstration

In this lesson, you will use Electric City to demonstrate what could happen when supply does not meet the predicted demand. To make this demonstration intuitive and impactful for students, it is essential to set up and test materials before class begins. The schematic shown below, left, indicates the electrical connections needed to make the demo function properly, and the next image (below, right) indicates a suggested physical layout for the demo.

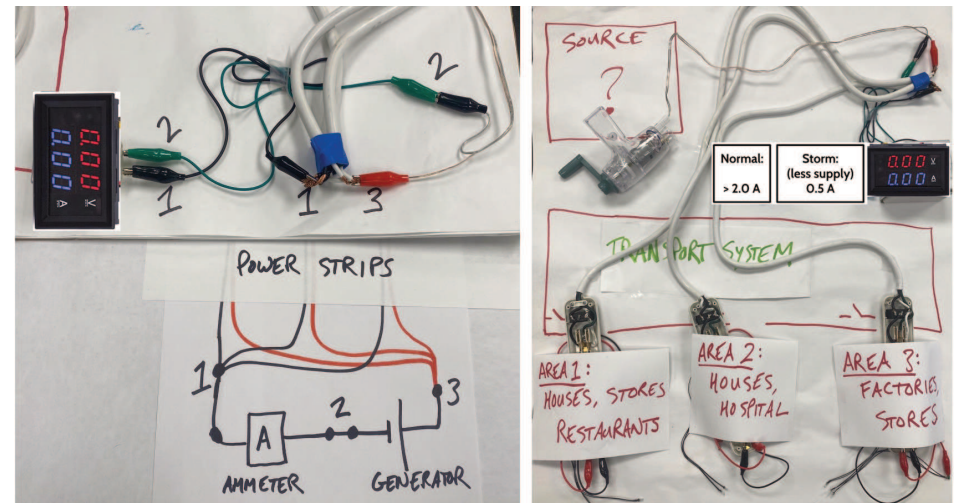
Preview <https://youtu.be/ZMOOuWmszic> beforehand to get an idea of what this demonstration will look like. The “storm (less supply)” value will likely be different in this video than for your equipment, but the takeaways are the same.

An ammeter is used to measure “total supply and demand” going to all three “buildings” or “areas”. Each building or area is set up on its own power strip so it can be turned on or off. The high-power hand-crank generator (**not** the homemade generator) is used as an energy source, and incandescent bulbs (**not** LEDs) are used to indicate devices that use energy in the three buildings or areas.

Make sure one area has been designated ahead of time as a “hospital”. For the conversation about equity of power distribution for people who happen to live near essential services, we recommend designating two areas as “houses” or “residential”, with one of these areas containing the hospital.

IMPORTANT: Check the connections between the generator, ammeter, and the three power strips with light bulbs ahead of class, to ensure that the demo works properly:

- If you have an ammeter or a good-quality multimeter, you can use it in these investigations. Otherwise, refer to *Ammeter Construction Directions* from Lesson 6 for instructions on how to build your own ammeter from parts.
- Use the schematic diagram to connect the ammeter and generator to the power strips. Notice that the white wires of the power strips are twisted together, and the black wires are twisted together. This allows for a consistent connection to all three power strips when the switches are on.
- Check that the lights on the power strip turn on when you crank the generator. If they do not, then troubleshoot:
 - Flip the switches on the power strips.
 - Check the alligator clip connections from the power strip to the bulbs--if a single bulb isn't lighting, try swapping out clips and bulbs.
 - Check the connection to the generator--try connecting a single bulb with alligator clips, and (gently!) turn the crank to confirm that the bulb lights.
- Check that the ammeter value goes into the positive range when you crank the generator to turn on lights. If it does not:
 - If the ammeter drops toward the negative range, then reverse the connections on the ammeter and try again.
 - If the ammeter reading doesn't change at all (but the lights turn on), check that the connections to **all three** power strips are going through the ammeter, as shown in the schematic.
- Check that the ammeter registers a meaningful value when all three power strips are turned on.



- Crank the generator with (a) all three switches on, (b) two switches on, and (c) only the “hospital area” switch on. **Find a value where the lights don’t turn on (or just barely turn on) with two switches but do turn on when only the hospital is on.** Write this value down as a “storm (less supply)” maximum value to use in your demo. In the image shown (with two bulbs at the hospital and two or three bulbs in other areas), this maximum value is 0.5A, but it may be slightly different for your setup.
- **Note:** During the demonstration, students are encouraged to “increase demand” as we saw happen during the storm in Texas. Test this ahead of time: students should be able to add “demand” (a bulb) to the hospital power strip, and the generator should be able to light up the hospital circuit alone with less than your “storm (less supply)” maximum value.

Day 2: Looking for Correlations Lab

For this lab, students will need access to at least one computer per group of students to run the online platform CODAP. Make sure the link works, and spend a couple of minutes familiarizing yourself with CODAP on your own before the lesson (<https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FbDWoSkkcv8T1sfwwgGva%2Ffile.json>).

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to build ideas related to the following elements of disciplinary core ideas:

- **PS3.B.4 Conservation of Energy and Energy Transfer.** The availability of energy limits what can occur in any system. (HS-PS3-1)
- **ETS1.B.1 Developing Possible Solutions.** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

In this lesson, students will determine that even though at some scales it appears that county-level variables might determine who lost power in Texas in February 2021, this relationship is not supported statistically. It is important to emphasize that there are limitations on our analysis, so we should not draw conclusions too quickly. In Lesson 8, students will listen to a podcast and obtain information about what this same analysis can tell us when performed at a different scale (**CCC 3.3 Patterns:** Patterns observable at one scale may not be observable or exist at other scales). They will also learn that even if there is no statistical correlation tying outage disparities between neighborhoods to most of the factors we investigate, power outages still have an inequitable impact on people in low-income neighborhoods, due to existing disparities.

Students will encounter or co-develop definitions for the following words in this lesson: *hypothesis, correlation, r^2* . **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students will determine the statistic of correlation and use it to make inferences about whether there is a correlation between two variables, but they will not determine the statistical significance of that correlation. This choice was made due to constraints on time and on common digital tools, and because significance is not explicitly treated in the performance expectations associated with this unit. However, you may decide to take this exercise a step further and discuss statistical significance.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

5 min

MATERIALS: science notebook

Navigate into the work by deciding to put the pieces together. Project slide A and read the text at the top aloud: *Let's put the pieces together to model how insufficient supply of energy could have affected energy transfer into certain communities in Texas when the temperatures dropped.*

Have students pull out all the energy transfer models they have made so far: for the windmill, natural gas power plant, generator, and grid (or wires). Give them a moment to look through these models before responding to the questions on the bottom of the slide. See the table below to guide this brief discussion.

Suggested prompt	Sample student response
<i>Which subsystems of the electric grid should we include in our models?</i>	The generator or the power plant. (Students may also suggest including the energy source as a separate system.) The transport system or the wires. (Students may also decide to include substations.) The community (or buildings, homes, and so forth).
<i>At what scale or scales?</i>	We don't really need to model at the particle scale, we can just include macro-scale systems. Electron interactions might be involved in ways we don't understand, so we want to model electrons in the wires.
<i>How will we bound our system to show energy loss?</i>	The air and the environment will be outside the system, but the power plant, transport system and buildings will be inside.
<i>What kinds of energy loss do you think we may end up modeling?</i>	Energy loss through heat in the wires. Energy loss through light, heat, and/or sound in the buildings. Energy loss at the power plant.
<i>What will you do to make sure we can see how much energy is lost, and whether sufficient energy is arriving at the homes and other buildings?</i>	We will make sure to quantify our models.

2 • MODEL IN GROUPS

10 min

MATERIALS: science notebook, sheet of three-hole-punched paper, *Progress Tracker*

 **Model in small groups.** Present slide B. Arrange students in groups of 3 to create a model showing how insufficient supply of energy could have affected energy transfer into certain communities in Texas when the temperatures dropped. Students can work on three-hole-punched paper that they can put in their notebooks. There is no one right way to produce this mode. We recommend modeling at the macro scale, including more than one power plant, a transport system, and at least two communities.

ASSESSMENT OPPORTUNITY

What to look for/listen for: Note that this task is designed to highlight gaps in our understanding. Do not expect students to accurately model what happens when there is not sufficient energy in the system, but rather to recognize that when supply does not meet demand the system will not function, and to use the appropriate conventions to make this clear.

- Students use the energy transfer conventions that we developed in Lesson 3 to represent systems, and energy transfer between systems.
- Which subsystems students choose to include may vary, but look for students to label systems clearly. At the least, students should include a power plant (or energy source), a transport system (or substation), and at least two communities (or homes/buildings in a community). (SEP: 2.3)
- Students use numbers, dots, or some other quantitative representation to show that the amount of energy entering the system is equal to the amount of energy available to homes, minus any energy lost to the surroundings.
- Students may choose to reduce supply, increase demand, or both, as long as students show that supply did not meet demand.
- If students choose to show energy loss to the surroundings, this loss is reflected in the amount of energy available to homes. (CCC: 5.2, 5.3)
- Students indicate that insufficient supply results in power loss, either by labeling the appropriate buildings as blacked out, using an X to indicate no energy transfer, erasing (or not drawing) lines indicating energy transfer, and so forth. (DCI: PS3.B.4)

What to do:

- Students have modeled all these systems before. Remind them to look back at their *Progress Tracker* to see examples of energy transfer diagrams, and of the systems they will need to model now.
- Ask probing questions to encourage students to quantify energy transfer, for example, *How does this model show that the supply of energy is reduced? Is there a way you can quantify the energy to make that more clear?*
- Encourage students to quantify energy transfer over the arrows in their diagrams, rather than quantifying the energy in a single subsystem.
- Use probing questions to encourage students to show the effect of diminished supply on homes, for example, *Can you show what happens in the communities when the energy transfer is this low?*

Building toward: 7.A Develop a model showing how insufficient supply entering the system could lead to reduced energy transfer into certain communities in Texas when the temperatures dropped, resulting in buildings losing power. (SEP: 2.3; DCI: PS3.B.4; CCC: 5.2, 5.3)

3 · CREATE A CONSENSUS MODEL

10 min

MATERIALS: chart paper, markers

Start building the poster by deciding which systems to model. Project slide C, which presents a series of decisions the class will need to make as part of modeling:

- *What systems to include in our model, and how energy transfers through them*
- *How to quantify energy transfer*
- *How to distribute demand across areas*
- *How to distribute supply across areas*

Direct the class's attention to the first bullet. Ask a student to suggest a subsystem to include in our model. Then ask the rest of the class whether they included that system. If students do not raise their hands, ask them why they chose not to include that system, or whether they perhaps included it under another name. Then ask the class whether we should include that system in our model. If it is a subsystem other than "power plant," "transport system," or "community," push students to justify their reasoning, but be ready to include it in the model if the justification is strong and the class has broad consensus that it should be included.

Record the systems the class agrees on using a piece of chart paper labeled "Consensus Model for Energy Transfer during the Crisis". Repeat this process until the class agrees that the important systems are on the model.

Represent and quantify energy transfers in the model. At this point, students should feel that tracing the direction of energy transfer is pretty intuitive, so add arrows between these systems on the poster and check in quickly with students to make sure they agree.

Then ask how students chose to quantify energy transfer. It will be impossible to reach consensus on exactly which numbers to use, but establish the following before coming up with a system:

- Whether it is necessary to also include normal conditions to illustrate the change, and if so, how to do that (either with a second diagram or a second color)
- Whether we should quantify using numbers, or dots, or something else
- Whether supply should be reduced, demand should be increased, or both
- Whether demand should be distributed equally across neighborhoods, or in some other way to indicate differences across neighborhoods
- How to distribute insufficient supply, given that we do not yet know that the power companies will simply cut off power to an entire neighborhood to allow sufficient energy to supply other neighborhoods

Highlight what we do not know about how limited supply is distributed during a crisis. The last two bullets on the slide (how to distribute supply and demand) will be the most difficult to model; highlight areas of disagreement there using question marks. Say, *It sounds like we feel pretty confident about the systems involved, and how energy transfers, and how to model supply and demand. But we are still unsure how to model what actually happens in the grid when supply does not match demand.*

Motivate using Electric City to test our ideas. Present slide D. Say, *We are not sure how to model what actually happens in this case, because our diagrams don't represent that aspect of the system.*

Pose the question on the slide: *How could we test our models to see what actually happens to an electric grid when supply cannot keep up with demand?* Accept all student ideas, but highlight ideas about using physical tests (with wires and so forth) to try these things out. Students might also suggest a simulation, or modifying our diagrammatic models.

4 · USE ELECTRIC CITY TO TEST OUR IDEAS

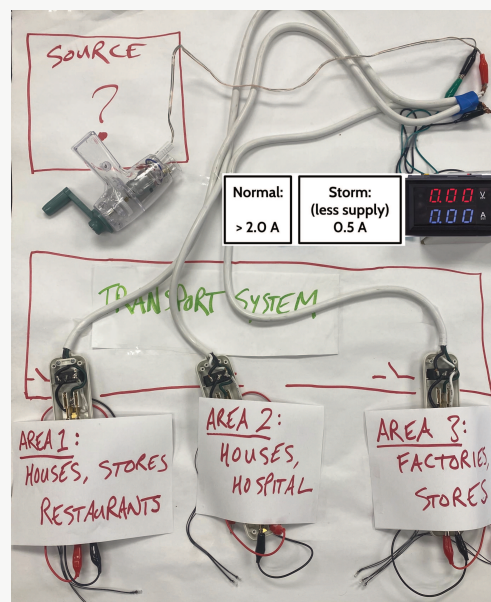
15 min

MATERIALS: Electric City Decisions Demonstration

Set up the demonstration in advance. See the Materials Preparation section for detailed instructions on how to set up and troubleshoot this demo. Do not plan to troubleshoot during class, as students will lose interest in the demo and its potential impact will be lost.

Use Electric City to model an energy supply crisis. Present slide E. Gather the class around the Electric City demonstration. Reorient students to the setup by asking them to map the model to the systems we know about in real life (power plants, buildings, wires, and so forth). Then pose the first question on the slide, as shown in the table below.

Orient students to the ammeter. The last time we looked at Electric City, we weren't using an ammeter to measure current. Point out that we have the chance to measure "demand" in our city using the ammeter; the higher the value on the ammeter, the more "demand" is being met.



Suggested prompt	Sample student response	Follow-up question
<i>How can we model the effect of the cold temperatures in Texas on supply and demand using Electric City?</i> <i>We could make the classroom colder.</i>	We could add more light bulbs. Will this affect supply or demand in our Electric City model in the same way it affected Texas in 2021? What could we do to simulate the effect the cold temperatures had on supply and demand?	<i>What would this help us model in Texas?</i>

Suggested prompt	Sample student response	Follow-up question
<i>We could reduce the amount of energy we put into the system by using weaker batteries, or cranking the generator less.</i> <i>The power plants couldn't produce as much energy, so this means that the current measured on the ammeter would be less.</i>	What would this help us model in Texas? Let's choose a value to think of as our "maximum supply" during the storm. How about (0.5A)? (If you chose a different "storm (less supply)" value in your setup, provide this value here.)	

Once the class has agreed on increasing demand by adding several more bulbs to the city, make these adjustments to the setup, and crank the generator. Watch the lights turn on and notice the increased ammeter value--if the measurement is above the maximum value, that is fine, but students should take note that if the current is in fact greater, we don't have a way to know.

Once the class has agreed on decreasing supply by cranking the generator more slowly--keeping the value below the "storm (less supply)" value (0.5A in the image shown, and in 200mA example video)--ask students to make observations using the second prompt on **slide E**: *What do you notice and wonder?* Listen for ideas about the lights not going on.

Make decisions about how to keep the lights on in the hospital. Focus students on what we could do to keep the lights on in some places.

Pose the last prompt on the slide: *What do we need to do to keep the lights on in the hospital?*

- Students might suggest **increasing power**, or adding another power plant. Remind them that the supply in Texas was limited. Listen for students to suggest reducing supply, and ask them how we can do that.
- Students might suggest **turning out some lights**. Ask them how the power companies could have done this in Texas. Listen for suggestions about social media requests, or using news broadcasts to ask people to turn off lights.
- Students might suggest **cutting power** to some buildings. Listen for this idea and highlight it. Ask, *What could we do as someone with decision-making authority, without going into individual buildings because that is trespassing, to cut the power?* Listen for students to suggest unplugging a path to a certain neighborhood, or using a power strip to cut power to that neighborhood.

When students suggest cutting power to another area, do so in Electric City. You should be able to turn on the lights in the building designated as the "hospital".

ALTERNATE ACTIVITY

You can use the video <https://youtu.be/ZMOOuWmszic> to do these demonstrations if you are tight on time and/or space, but we highly recommend that you give students a chance to see the effect in Electric City in the classroom. If you do use the video, try playing it without sound and pausing it to ask students questions about what is happening. The narration of the video gives away much of the thinking that they should be doing themselves.

5 · NAVIGATE BY CONSIDERING OUR DECISION-MAKING

5 min

MATERIALS: None

Turn and talk about human decision-making. Pose the prompts on **slide F** as a Turn and Talk:

- *How could human decisions like the ones we just made have affected who lost power in Texas in February 2021?*
- *Were these decisions fair? Why or why not?*

If there is time, elicit ideas from 2-3 student pairs before leaving class. Listen for them to suggest that humans at the power company probably had to decide how to cut power to people. Accept all ideas for the last question about whether the decisions were fair. If students are upset because they believe these decisions to be unfair, make space for them to voice their opinions right now, and forecast that we will spend more time thinking about how fairness is a part of engineering decision-making. Make it clear that students' concerns about ethics and decision-making have a rightful presence in the science classroom, even if we do not have the time to dig deeply today. *

* ATTENDING TO EQUITY

Social and Emotional Learning: Giving students a chance to consider what they think is fair in engineering decision-making can help support the development of students' **self-awareness**, one of the Collaborative for Academic, Social, and Emotional Learning (CASEL) five core competencies. *Self-awareness* describes the ability to understand one's own emotions, thoughts, and values and how they influence behavior across contexts. Students will continue to develop self-awareness across Lessons 8-10. For more support around social and emotional learning, visit the video <https://casel.org/>.

End of day 1

6 · NAVIGATE WITH A STOP AND JOT

5 min

MATERIALS: science notebook

Stop and jot about decision-making. Remind students that last time, we used Electric City to model Texas in February 2021 by reducing supply and increasing demand. Project **slide G** and pose the prompts as a Stop and Jot:

- *What did we need to do to keep the lights on in the "hospital" in Electric City?*
- *What kinds of decisions do you think power companies made during the blackout, and why?*

Then ask students to share out.

7 · ANALYZING DATA AS A CLASS

15 min

MATERIALS: poster of questions from slide I (optional), computer or device with access to <https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FbDWoSkKcv8T1sfwwgGva%2Ffile.json>

Discuss a hypothesis and make a prediction as a class. Project slide H. Discuss the following hypothesis: *During the Texas power crisis of February 2021, people were less likely to lose power in counties where there were more hospitals.* Then ask students to make a prediction: *Do you think the data will support this hypothesis? Why or why not?* Accept all ideas.

Orient to CODAP and run a correlation analysis between hospitals and percent out. Project slide I and read its instructions aloud to forecast what we will do next. Be ready to navigate away from the slide to orient to CODAP, either by revealing the poster you prepared ahead of time with the questions from slide I, or by flipping back and forth between projecting CODAP and the slide:

- *Is there a correlation between the two variables we chose to look at?*
- *What conclusions can we make about our hypothesis from this analysis?*
- *Does this analysis tell us anything about what caused the crisis?*

Project <https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FbDWoSkKcv8T1sfwwgGva%2Ffile.json> on a computer where the whole class can see. Ask students what they notice. Show them the four data sets related to hospitals, and ask them to consider how these data might differ:

- hospitals
- acute-care beds
- hospitals per 100,000 people
- acute-care beds per 100,000 people

Focus on a variable of interest related to hospitals. Listen for students to suggest that per 100,000 might be a better variable. If necessary, you can try dragging all four variables to the graph's x-axis and let them observe the difference. Focus on one (or both) of the two variables that are per 100,000, explaining that this allows us to control for population size, then ask students if they notice a pattern. Accept all ideas. Students may notice a very slight negative correlation, particularly for the acute-care beds per 100,000.

Demonstrate and explain a least squares line. Click the ruler icon to the right of the graph, and then check the box marked "Least squares line". Explain that this will allow us to draw a line that best fits the data using a computer algorithm.

Introduce r^2 as a value to estimate how well the line fits the data. Show the r^2 value and ask students whether they have ever used a value like this before. Explain that the r^2 value on the line of best fit is known as the correlation coefficient; if r^2 is close to 1, the line is a very good fit, and the chosen variable helps us predict how many people lost power in a given county; if r^2 is close to 0, the line is not a good fit, and the chosen variable does not help us predict how many people lost power. This explanation is written out on students' handouts for the next activity, so they will have another opportunity to grapple with these ideas.

Help students interpret the complexity of the result. Point out that r^2 is pretty low, closer to zero than to 1. Explain that this doesn't mean hospitals or acute-care beds don't help us explain the pattern of power outages, but if there is a correlation, it probably isn't the most important variable--it is probably one of many, many variables that can help us understand what happened. Some other variable might have been much more important, and will thus be much more predictive.

ADDITIONAL GUIDANCE

If students ask, you may need to explain that most hospitals have generators to supply power in an emergency, but the power company was still concerned about making sure hospitals got enough electricity, because power outages due to cold could last for so long. Had the electricity supply in Texas been stretched too far, it could have caused catastrophic grid failure that might have lasted for months. Whether this was a fair decision to make is up for debate, as many people, particularly in those neighborhoods where people face racial and economic health disparities, still lost power they needed for life-saving medical equipment they use at home.

Turn and talk about possible differences between counties. Project slide J. Pose the prompt on the slide as a Turn and Talk: *What else do you predict might be different about the counties that lost a lot of power versus the counties that did not lose as much power?* You do not need to ask students to share out.

8 · ANALYZE DATA IN SMALL GROUPS

15 min

MATERIALS: Looking for Correlations

 **Complete the handout in small groups.** Project slide K. Arrange students in groups of 2-3. Distribute *Texas County Data Analysis* to each group, and tell them to work together to choose a variable for analysis using CODAP. Move around the classroom to support students as they work. Check *Texas County Data Analysis Key* for ideas about what to look for and how to support students. You will collect the handout at the end of the day to provide more focused feedback. *

ASSESSMENT OPPORTUNITY

When to check for understanding: Collect *Texas County Data Analysis* at the end of day 2.

What to look for/listen for:

- Use *Texas County Data Analysis Key* to look for students to explain why their variable might be related to power loss by making connections to human engineering decision-making or to natural causes (Question 2). (DCI: ETS1.B.1)
- Use the key to look at the students' hypotheses (Questions 3-4), their data analysis (Questions 4-8), and their current thinking about limitations (Question 9). (SEP: 1.6, 4.2, 4.3)
- Use the key to look at the way students are talking about correlations (Questions 6-8). (CCC: 2.1)

What to do:

- Use the key to provide focused feedback based on students' responses at multiple levels.

Building toward: 7.B.1 Develop and test a correlational hypothesis to investigate trade-offs inherent in making decisions about energy, and then consider limitations on this analysis to motivate seeking information about patterns at a smaller grain size. (SEP: 1.6, 4.2, 4.3; DCI: ETS1.B.1; CCC: 2.1, 3.3)

* ATTENDING TO EQUITY

It is important to be sensitive to students from low-income neighborhoods, or neighborhoods with a high percentage of people of color, who may not feel comfortable talking about disparities in a personal way. Never ask students to reveal where they live or what kind of neighborhood they live in; but if they want to share these details, listen, and validate their contributions as valuable to the discussion. Make it clear that although students do not need to engage in these conversations or speak for their communities, students' ideas about social disparities and what is fair or unfair are welcome in the science classroom when they move our thinking forward about a design problem or phenomenon.

9 · DISCUSS LIMITATIONS OF THE DATA SET

5 min

MATERIALS: *Texas County Data Analysis*

Briefly discuss limitations of data at a county level. Project slide L and read the text aloud: *The conclusions scientists can make are limited by the available data.* Remind students that this was addressed in Question 9 of *Texas County Data Analysis*. Then pose the slide prompts to the class:

- What limitations might be introduced by the fact that our data are grouped by county?
- What other limitations did you notice?

Elicit student responses. Accept all ideas and don't play guess-what's-in-my-head, as this will be explored more in Lesson 8. But highlight ideas related to scale or grain size, for example:

- We might be able to see patterns on a smaller scale.
- Maybe the counties are too big.
- Maybe there are cities/towns/communities that go across more than one county.
- Maybe there are counties that go across more than one city/town/community.

Use a Turn and Talk to get students thinking about patterns within a county. Project slide M. Pose the prompt as a Turn and Talk: *What patterns do you predict we will see if we could “zoom into” the counties where some people, but not all, lost power?*



Look quickly at satellite imagery. Present slide N. Make sure students understand that a county is an arbitrary political boundary. Help them see that the satellite imagery maps onto an area that goes across the counties in the Texas map, and that the counties may not capture the details of who lost power where. Keep in mind that Lesson 8 will provide time to develop a better understanding of this; right now, the goal is simply to prime students to be thinking about what a county is, not necessarily to understand why satellite imagery might be more powerful for analysis than an analysis by county.

You can flip quickly between slides O-P to make the distinction between the two satellite images (January versus February 2021) more noticeable.

ASSESSMENT OPPORTUNITY

When to check for understanding: Use the conversation about limitations at the end of day 2 as an opportunity to pre-assess how well students understand the distinction between data at various grain sizes.

What to look for/listen for:

- Counties might not capture the details of how variables are distributed across communities. (CCC: 3.3)

What to do:

- If students are not making connections between grain size and what we can say about the data, do not push them now; but be ready to spend more time on this conversation after listening to Juan Pablo Carvallo's interview in Lesson 8.
- Consider finding data about the local county where your school is located, and looking at the distribution of communities on a map of that county in Lesson 8, after listening to the interview. Ask students, *What detail (from our experience) is lost about these communities when variables are reported only about the county?*

Building toward: 7.B.2 Develop and test a correlational hypothesis to investigate tradeoffs inherent in making decisions about energy, and then consider limitations on this analysis to motivate seeking information about patterns at a smaller grain size. (SEP: 1.6, 4.2, 4.3; DCI: ETS1.B.1; CCC: 2.1, 3.3)

10 • NAVIGATE

5 min

MATERIALS: *Progress Tracker*

Update *Progress Tracker*. Project slide Q to cue students to add to their *Progress Tracker*. Students may sketch an energy transfer model, or a representation of the Electric City demo, or they might talk about takeaways from the data analysis.

Navigate into the next lesson by forecasting an interview with an expert. Project slide R and read the text at the top aloud: *Next time, we will hear from an expert whose research group used satellite data to do the same kinds of analyses we did, but with data grouped at a smaller scale.*

Ask students to make predictions in response to the slide's prompt in a Turn and Talk:

- How do you predict these analyses will look similar to ours? How do you predict they will be different? Why?*

Additional Lesson 7 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

Several Common Core Math standards are targeted in this lesson from the category of **Statistics and Probability** and the domain **Interpreting Categorical and Quantitative Data**.

- **Interpret linear models (CCSS.MATH.CONTENT.HSS.ID.C.8).** Compute (using technology) and interpret the correlation coefficient of a linear fit.
- **Summarize, represent, and interpret data on two categorical and quantitative variables. (CCSS.MATH.CONTENT.HSS.ID.B.6c)** Represent data on two quantitative variables on a scatter plot, and describe how the variables are related. Fit a linear function for a scatter plot that suggests a linear association.

Students use a data visualization and analysis tool (CODAP) to identify the correlation coefficient of a linear fit between different demographic variables and the percentage of people who lost power in a given county in Texas during February 2021. In Lesson 8, students will explore issues with the scale of the data used to explain the lack of correlation, and reasons for why causal relationships cannot be drawn from a correlation in this context.

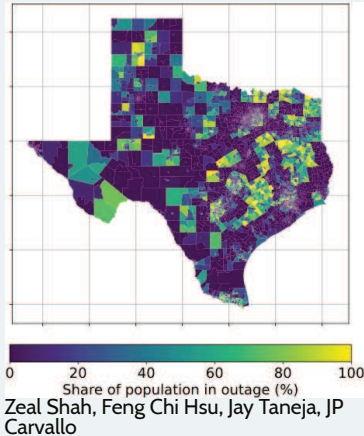
LESSON 8: Why do design solutions affect some people differently than others?

PREVIOUS LESSON We developed a model showing how insufficient supply entering the electrical system could lead to buildings losing power during a crisis. We tested our models using *Electric City*, and we noticed that to keep the lights on in one building, we needed to cut power to others. We used data to test for correlations with county-level factors that might have impacted decision-making in Texas in February 2021. We considered limitations on this analysis to motivate seeking information about patterns at a smaller grain size.

THIS LESSON

PUTTING PIECES TOGETHER

2 days



We listen to (and read the transcript of) a podcast featuring a scientist whose research group used satellite data to investigate patterns in who lost power in Texas. We discuss takeaways and put together the pieces we have gathered over the past several lessons. We realize that some tradeoffs associated with engineering design decisions affect people in different ways. We read about two fictionalized families in Texas and consider how existing disparities can make the impact of a power outage inequitable across communities. We consider battery power as a potential solution.

NEXT LESSON We will develop and revise energy transfer models to represent how batteries can make electric grid systems more reliable. We will quantify how much energy was needed to prevent the energy crisis in Texas 2021. We will use data from existing energy storage solutions to calculate the number of batteries needed and the costs associated with adding them to the system.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

8.A Integrate quantitative information, visual information, and audio (or text) to define some of the challenges and tradeoffs associated with a drop in energy supply driven by cold weather, and consider additional tradeoffs associated with making energy decisions. (SEP: 8.2; CCC/NOS: 5.2, 5.3; Science Addresses Questions About the Natural and Material World; DCI: ETS1.A.2, ETS1.B.1)

WHAT STUDENTS WILL FIGURE OUT

- An imbalance of energy supply and demand was the primary cause of the blackouts in Texas in February 2021.
- Design solutions for avoiding this in the future include interconnected power grids to increase supply when necessary, and winterizing gas pipelines and windmills.
- Across Texas, what neighborhood people lived in made an impact on whether they lost power.
- Power outages have an inequitable impact on people in communities where there are existing disparities.
- Throughout Texas, power companies made decisions to keep the power on in neighborhoods with “essential” buildings.
- All forms of energy production and other resource extraction have economic, social, environmental, and geopolitical costs and risks as well as benefits, which we will need to consider when making decisions about our own communities.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Navigate by prompting students to reflect on their questions.	A	
2	25 min		LISTEN TO AN INTERVIEW WITH AN EXPERT Have student groups listen to a podcast and discuss questions embedded in its transcript. Use <i>Listening Group Roles Reference</i> to scaffold this task (optional).	B	<i>Podcast Transcript: Interview with an Energy Expert, Listening Group Roles Reference</i> , headphones (optional), Engineering Design Tracker, computer or device with access to https://youtu.be/24vB0mqVkeA
3	15 min		BUILDING UNDERSTANDING Discuss takeaways from the podcast as a class, eliciting ideas about correlation, design solutions, and tradeoffs. Forecast that we will continue to think about tradeoffs inherent in decision-making about power.	C	Engineering Design Tracker
End of day 1					
4	5 min		NAVIGATE Discuss tradeoffs that we identified in our last class period to navigate back into the work.	D	
5	15 min		REVIEW THE READING'S INTRODUCTION Discuss how tradeoffs might affect people differently. Motivate the reading and have partners read the introduction.	E-F	<i>Texas Case Studies</i>
6	15 min		REVIEW THE READING'S CASE STUDIES Have students read the case studies individually and respond to the reflection questions. Then discuss the reading as a class.	G-H	<i>Texas Case Studies</i>
7	10 min		NAVIGATE: EXIT TICKET Assign the electronic Exit Ticket using an online form..	I-J	access to https://docs.google.com/forms/d/1lhV5AKCSuAfnQd6lIt6rVGf-v7z5TCLl6VUrrnZ5Jfg/copy
End of day 2					

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Podcast Transcript: Interview with an Energy Expert</i> <i>Listening Group Roles Reference</i> - headphones (optional) - Engineering Design Tracker <i>Texas Case Studies</i> - access to https://docs.google.com/forms/d/1lhV5AKCSuAfnQd6lIt6rVGf-v7z5TCLl6VUrrnZ5Jfg/copy	computer or device with access to https://youtu.be/24vBOMqVkeA	

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Access <https://youtu.be/24vBOMqVkeA> to make sure the podcast works. Prepare for students to listen to the podcast, either by gathering around a computer in separate areas, wearing headphones, or taking a walk and listening on their own before coming back together.

Before class, make a copy of <https://docs.google.com/forms/d/1lhV5AKCSuAfnQd6lIt6rVGf-v7z5TCLl6VUrrnZ5Jfg/copy>. Share the link to the **copy** that you make with students, **not** the link provided here; if you share this original link with students, that will create a new copy for each student, and you will not have access to their responses.

Lesson 8 • Where We Are Going and NOT Going

This lesson is designed to build ideas related to the following elements of disciplinary core ideas:

- **ETS1.A.2 Defining and Delimiting Engineering Problems.** 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. (HS-ETS1-1)
- **ETS1.B.1 Developing Possible Solutions.** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

This lesson is designed to support students toward the Next Generation Science Standards (NGSS) Nature of Science Understanding titled **Science Addresses Questions About the Natural and Material World** (Appendix H). The relevant understanding elements read:

- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Science knowledge indicates what can happen in natural systems--not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

5 min

MATERIALS: None

Prompt students to reflect on questions. Project slide A and read the text aloud:

- We will hear from an expert whose research group used satellite data to investigate patterns in who lost power in Texas.
- What questions do you still have that you hope this interview will help answer?

Ask 2-3 students to share out. Listen for questions about what determined whether or not someone lost power in Texas, or about how the analysis from the expert will compare to our analyses in the last class period.

2 · LISTEN TO AN INTERVIEW WITH AN EXPERT

25 min

MATERIALS: science notebook, *Podcast Transcript: Interview with an Energy Expert*, *Listening Group Roles Reference*, headphones (optional), Engineering Design Tracker, computer or device with access to <https://youtu.be/24vB0mqVkeA>

ADDITIONAL GUIDANCE

Juan Pablo Carvallo, the scientist featured in this podcast, is an electricity systems researcher. His group studied the crisis in Texas, and in our conversation, he provided insight into the disparities in who lost power that February, the injustices perpetrated against residents of color in particular, and the need for rethinking our systems to make sure something like this doesn't happen again.

Consider the context of your classroom before launching the podcast, and be prepared to provide social and emotional support for students who may have experience with racialized trauma. See *Unknown material with identifier: pe.l8.tref2* for additional support.

Listen to the podcasts in groups. Project slide B. Arrange students into groups of 4-5. Explain that we will listen to an interview with a researcher whose work could provide insight into who lost power in Texas that February and why. Note explicitly that the podcast includes terms that homogenize the diversity of experiences and backgrounds in marginalized populations in Texas. Remind students that terminology matters, and that we should always be thoughtful in how we interpret data, and the claims we make based on data.

Share the link to <https://youtu.be/24vB0mqVkeA>, and distribute *Podcast Transcript: Interview with an Energy Expert*. Direct groups to listen to (and/or read) the interview and to discuss the reflection questions embedded in the transcript.

When they are finished, tell students to respond in their notebooks to the following questions:

- What choices would you make if you had control of the power grid in your community during a crisis? *
- What kind of design solutions might have prevented people from having to make these decisions? Add these ideas to your Engineering Design Tracker.

* ATTENDING TO EQUITY

Social and Emotional Learning (SEL): Asking students to consider what choices they would make after considering their own emotions supports the development of another CASEL core competency that is highlighted over this unit's second lesson set: **responsible decision-making**. "Responsible decision-making" describes the ability to make caring and constructive choices about personal behavior and social interactions across diverse situations. This includes the capacity to consider ethical standards and safety concerns, and to evaluate the benefits and consequences of various actions for personal, social, and collective well-being. For more support around social and emotional learning, visit <https://casel.org/>.

Use *Listening Group Roles Reference* to support this work by assigning these suggested group roles:

- **Progress monitor.** This person periodically asks others to take the measure of the group's progress on the task.
- **Big ideas person.** The role of this person is to relate the podcast to the question(s) we are trying to answer.
- **Clarifier.** This person monitors everyone's comprehension of key science terms.
- **Questioner.** This person asks probing questions and revoices others' questions.
- **Conductor.** This person monitors the airtime of people in the group.

ALTERNATE ACTIVITY

As an alternative to breaking into groups, you can play this podcast in your classroom, and pause at intervals for a whole-group discussion of each set of embedded prompts. This may save time, particularly if the logistics of listening together are difficult.

3 · BUILDING UNDERSTANDING

15 min

MATERIALS: science notebook, Engineering Design Tracker

 **Discuss key takeaways from the podcast as a class.** Project **slide C**. Use the prompts to structure a Building Understandings discussion about the podcast, as shown in the table below. Make sure each group gets a chance to contribute by using a round-robin to elicit ideas about each question, and then asking other groups if they came to the same conclusions.

Suggested prompt	Sample student response
<i>What new ideas did your group take away from the podcast?</i>	(Accept all ideas; examples are listed below.) Extreme weather events are becoming more common, so we need to protect our grid. The blackouts in Texas were not fair, because more people in high-minority neighborhoods lost power. If the energy going into the grid is spread too thin, there would not be enough energy in the system to keep electrons in the wires moving fast enough. This could cause the whole grid to shut down, causing weeks and weeks of widespread outages.
<i>Why couldn't Dr. Carvallo explain what had caused the patterns of who lost power?</i>	His group was able to find a correlation, but they did not have the right data to be able to make claims about causality.
<i>What design solutions did you add to your Engineering Design Trackers?</i>	Interconnected power grids to increase supply when necessary, winterizing gas pipelines and windmills, more solar panels on individual houses.
<i>What tradeoffs are involved in making decisions about whose power to cut in a blackout?</i>	The power company has to cut some power so not everyone loses power and the power plants don't break down, but that means some people will not have any power, and this could be dangerous.

Some students may want to discuss the ethical implications of what they heard in the podcast, as in the first row of the table above. Do not discourage them. Make it clear that concerns over ethics and decision-making have a rightful presence in the science classroom. Check in with students about how they feel about what they learned in the podcast, and validate their feelings if they are frustrated or angry after hearing Juan Pablo's findings.*

Navigate. Forecast that in our next class period, we will pick up on this conversation and think more deeply about tradeoffs that are inherent in making decisions about power.

* ATTENDING TO EQUITY

Social and Emotional Learning: Giving students a chance to consider what they think is fair in engineering decision-making can help support the development of students' **self-awareness**, one of the Collaborative for Academic, Social, and Emotional Learning (CASEL) five core competencies. *Self-awareness* describes the ability to understand one's own emotions, thoughts, and values and how they influence behavior across contexts. Students will continue to develop self-awareness across Lessons 9 and 10. For more support around social and emotional learning, visit <https://casel.org/>.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Listen for students to reference ideas they heard in the podcast, in conjunction with the graphs they saw projected over the podcast (or in the accompanying handout). (DCI: ETS1.A.2, ETS1.B.1)
- Listen for students to identify at least one tradeoff related to decisions made by the power company. The most obvious tradeoff is related to cutting power to protect essential buildings and power plants at the expense of people in certain communities. But listen for more nuanced tradeoffs as well, such as the tradeoff between weatherizing power plants versus cost, or between reliability in a storm versus using wind/solar power to avoid burning fossil fuels. (SEP: 8.2)
- Listen for students to recognize that if energy going into the grid is spread too thin, there will not be sufficient energy in the system to keep electrons in the wires moving fast enough. This could cause the whole grid to shut down, causing weeks of widespread outages. (CCC: 5.2, 5.3)

What to do:

- Use probing questions to help students connect ideas they heard in the podcast to the graphs projected over the audio (and available in the handout). For example, ask, *Did you see any data representations that supported that idea?*
- Help students identify tradeoffs by reminding them of what a tradeoff is. For example, say, *Tradeoffs are compromises in a situation where not everyone can get what they want or need. Usually by trying to meet one criterion, that means that we cannot fully meet another criterion, or vice versa.*
- When you talk about electrons moving through wires, use hand gestures to indicate that the electron motion is more like a wiggle, rather than linear motion. Remind students what they saw in the simulation in Lesson 6.

Building toward: 8.A.1 Integrate quantitative information, visual information, and audio (or text) to define some of the challenges and tradeoffs associated with a drop in energy supply driven by cold weather, and consider additional tradeoffs associated with making energy decisions. (SEP: 8.2; DCI: ETS1.A.2, ETS1.B.1; CCC/NOS: 5.2, 5.3; Science Addresses Questions About the Natural and Material World)

End of day 1

4 · NAVIGATE

5 min

MATERIALS: None

Navigate by discussing tradeoffs. Project **slide D** and ask students to turn and talk about the prompt. Look for students to share ideas similar to those they shared at the end of the last class period, as shown in the table below.

Suggested prompt	Sample student response
<i>What tradeoffs did we identify last time that are involved in making decisions about whose power to cut in a blackout?</i>	If the power company cuts power to help some people, other people will not have any power, and this could be dangerous.

5 · REVIEW THE READING'S INTRODUCTION

15 min

MATERIALS: science notebook, *Texas Case Studies*

Discuss how tradeoffs might affect people differently. Project **slide E**. Read the text at the top of the slide to frame the discussion: *We have identified several tradeoffs that required power companies in Texas to make difficult decisions in 2021.* Instruct students to respond to the slide's prompt in their notebooks, and then to be ready to talk about it: *How do you think these tradeoffs might affect some people differently than others?*

After about 2 minutes, ask students to move to a new place in the room to talk about that question with a new partner. Listen in on these conversations. You may hear things like:

- More people in the neighborhoods where there are fewer hospitals will lose power.
- Some people might have more resources to deal with power outages than others.

Motivate the reading. Explain that sometimes to understand the real implications of design decisions on people, and in particular how tradeoffs affect different people, it is important to learn about real stories from real people. Tell students that you have two stories for them to read and reflect on. They are not true stories, but they are based on details of real stories from the Texas power crisis. Distribute *Texas Case Studies* to each student.

Go over the reading's introduction in partners. Project **slide F**. Explain that the case studies we will read have an introduction that could help us put some of the pieces together. Have students follow the directions on the slide:

- *Read the introduction to Texas Case Studies.*
- *Underline passages that help answer the question of why some people lost power in Texas and others did not.*

6 · REVIEW THE READING'S CASE STUDIES

15 min

MATERIALS: science notebook, *Texas Case Studies*



Read and respond to the case studies individually. Project slide G. Have students return to their original seats if they would like. Ask them to read the rest of *Texas Case Studies*--the stories of Family A and Family B--on their own, and then respond to the reflection questions at the bottom of the handout in their notebooks:

1. How were the experiences of these two families different?
2. If everyone loses power for the same amount of time, why do you think the experience is different for people with different social identities, and in different economic circumstances?

Hold a Building Understandings discussion. Project slide H. Hold a discussion about how existing disparities make the experience of a power outage very different for people with different resources available to them. Because of this, even if outages are equally distributed, the effects of those outages may be drastically inequitable. Use the prompts on the slide to structure the discussion, as shown below.

Suggested prompt	Sample student response
<i>How were the experiences of these two families different?</i>	One family had access to more resources and were able to make a fire, pretend they were camping, and leave town when things got bad. One family didn't have as many resources, and things got very dangerous for them before they found a warming center.
<i>What are some other difficult decisions about power that involve making tradeoffs?</i>	Which sources to choose. How much electricity to use, because it impacts the planet/animals. Whether to use nuclear power, because it might be dangerous. Whether to use coal, because it helps the local economy but can also make people sick. Renewable energy sources like wind and solar tend to be unreliable over the course of a day or a year.
<i>How might these tradeoffs affect some people more than others?</i>	Some people might live closer to the power plants and be more affected by pollution. Some people might live in a place that depends on coal or another non-renewable resource for jobs. Energy sources that will be good for Earth, like solar or wind, might not work all the time for people who live in places with no sun or very little wind.

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This lesson is designed to support students toward the Next Generation Science Standards Nature of Science Understanding titled "Science Addresses Questions About the Natural and Material World" (Appendix H). The relevant understanding element reads: "Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. Science knowledge indicates what can happen in natural systems--not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues."

* ATTENDING TO EQUITY

Social and Emotional Learning: Giving students space to consider what these power outages were like can help support their development of **social awareness**, one of the Collaborative for Academic, Social, and Emotional Learning (CASEL) five core competencies. *Social awareness* describes the ability to understand the perspectives of and empathize with others, including those from diverse backgrounds, cultures, and contexts. It is important to help students empathize, but also to support students in not essentializing the people in these stories. Point out that no social category is a monolith, and that many of them interact with one another and with other social and professional identities.

As before, make space for students to share emotional responses to the reading, and validate those concerns. * Remind students that there are problems inherent in engineering design that require science ideas to solve, but that also require subjective human decision-making based on human value systems. *

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students recognize that power outages have an inequitable impact on those people in communities where there are existing disparities. (CCC/NOS: 5.2, 5.3; Science Addresses Questions About the Natural and Material World)
- Students begin to brainstorm tradeoffs related to choosing which energy source to use (e.g., renewable versus reliable; building close to a city versus pollution in vulnerable neighborhoods). (DCI: ETS1.A.2, ETS1.B.1)

What to do:

- Focus students on the two families in the reading before attempting to generalize, and do not force a conclusion. If students can connect to the stories and understand how circumstances affect experience, they are building a foundational understanding and developing the core social and emotional competency of *social awareness*.
- Help students identify tradeoffs by reminding them of what a tradeoff is. For example, say, *Tradeoffs are compromises in a situation where not everyone can get what they want or need. Usually by trying to meet one criterion, that means that we cannot fully meet another criterion, or vice versa.*

Building toward: 8.A.2 Integrate quantitative information, visual information, and audio (or text) to define some of the challenges and tradeoffs associated with a drop in energy supply driven by cold weather, and consider additional tradeoffs associated with making energy decisions. (SEP: 8.2; DCI: ETS1.A.2, ETS1.B.1; CCC/NOS: 5.2, 5.3; Science Addresses Questions About the Natural and Material World)

7 · NAVIGATE: EXIT TICKET

10 min

MATERIALS: access to <https://docs.google.com/forms/d/1lhV5AKCSuAfnQd6It6rVGf-v7z5TCLl6VUrrnZ5Jfg/copy>

Consider additional solutions for a crisis. Present **slide I**. Read the first prompt aloud: *Think back to Electric City. Imagine we could not turn the generator. What other solutions could we use to power our model city even if the generator is not functioning?* Look for students to suggest using the battery we used in Lesson 2. If students are stumped, follow up with, *Was the generator the only way we could get the lights to turn on in Electric City? What else have we used?*

Then read the slide's second prompt aloud: *Could we apply a similar solution to prevent a crisis in real life, and avoid having to make inequitable tradeoffs?* Accept all ideas, and suggest that we explore this more next time.

 **Assign the electronic Exit Ticket.** Before class, make a copy of <https://docs.google.com/forms/d/1lhV5AKCSuAfnQd6It6rVGf-v7z5TCLl6VUrrnZ5Jfg/copy>. Share the link to the copy with students (do **not** share the original link provided here, as that will create a new copy for each student, and you will not have access to their responses). Present **slide J**. Give students at least five minutes to complete the electronic Exit Ticket.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Use *L8 Electronic Exit Ticket Key* to assess student work.

What to do: This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together. It assesses lesson-level performance expectations from Lessons 7 and 8.

Building toward:

7.A Develop a model showing how insufficient supply entering the system could lead to reduced energy transfer into certain communities in Texas when the temperatures dropped, resulting in buildings losing power. (SEP: 2.3; CCC: 5.2, 5.3; DCI: PS3.B.4)

7.B Develop and test a correlational hypothesis to investigate tradeoffs inherent in making decisions about energy, and then consider limitations on this analysis to motivate seeking information about patterns at a smaller grain size. (SEP: 1.6, 4.2, 4.3; ETS1.B.1; CCC: 2.1, 3.3)

8.A Integrate quantitative information, visual information, and audio (or text) to define some of the challenges and tradeoffs associated with a drop in energy supply driven by cold weather, and consider additional tradeoffs associated with making energy decisions. (SEP: 8.2; DCI: ETS1.A.2, ETS1.B.1; CCC/NOS: 5.2, 5.3; Science Addresses Questions About the Natural and Material World)

Additional Lesson 8 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

This lesson targets a Common Core ELA standard from the category of **Integration of Knowledge and Ideas**.

- **CCSS.ELA-Literacy.RST.11-12.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) to address a question or solve a problem.

Students read a transcript and listen to an interview with an energy professional, and use details from that interview to help answer the question of why some people in Texas lost power and others did not.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

This is the CCMS-related idea that is used to support sensemaking in this lesson:

Statistics and Probability

- **CCSS.MATH.CONTENT.HS.S-ID.9. Interpreting Categorical and Quantitative Data:** Distinguish between correlation and causation.

In Lesson 7, students found a lack of correlation between the variables they investigated and the patterns in the distribution of blackouts in Texas they observed. In this lesson, students listen to a podcast in which a scientist provides additional reasons for why it is hard to find a correlation with the type of data students used, and discusses the distinction between correlation and causation.

LESSON 9: How can energy storage make our systems more reliable during an energy crisis?

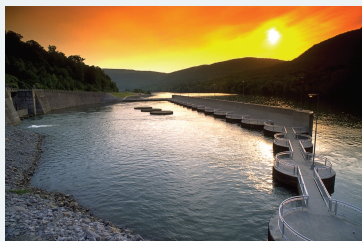
PREVIOUS LESSON

We listened to a podcast featuring a scientist whose research group used satellite data to investigate patterns in who lost power in Texas. We read about two fictionalized families in Texas and considered how existing disparities could make the impact of a power outage inequitable across communities. This got us wondering about other tradeoffs associated with making energy decisions. We considered battery power as a potential solution.

THIS LESSON

INVESTIGATION

2 days



Tennessee Valley Authority

We develop and revise energy transfer models to represent how batteries can make electric grid systems more reliable. We quantify how much energy was needed to prevent the energy crisis in Texas 2021. We use data from existing energy storage solutions to calculate the number of batteries needed and the costs associated with adding them to the system. We add to our Engineering Design Trackers, and wonder about the non-financial costs of design solutions.

NEXT LESSON

We will read about tradeoffs associated with various energy sources. We will identify the electricity-related values of diverse interested parties. We will begin developing a plan for improving electricity infrastructure in our community.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

9.A Develop an energy transfer model to predict the stability in the distribution of electric energy when batteries are present and absent from the system. (SEP: 2.3; CCC: 7.4; DCI: PS3.B.1, PS3.B.4)

9.B Apply ratios, rates, percentages, and unit conversions to calculate the costs and land area of use of a design solution to evaluate its feasibility for preventing an energy crisis like the one in Texas in 2021. (SEP: 5.5; DCI: ETS1.B.1; PS3.D.1; CCC: 3.1)

WHAT STUDENTS WILL FIGURE OUT

- All forms of energy production and other resource extraction have economic, social, environmental, and geopolitical costs and risks as well as benefits, which we will need to consider when making decisions about our own communities.
- Design solutions that store excess energy can prevent an energy crisis by bridging the gap between energy demand and supply.
- Energy storage systems can make an electric grid more reliable by providing power when the energy supply drops.

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		NAVIGATE Review the design solutions that could help power companies generate enough electricity through a crisis.	A	
2	20 min		INTEGRATE A BATTERY INTO THE ENERGY TRANSFER MODEL Have students model how adding a battery to a system affects its reliability. Ask students to switch a model with a partner and give feedback.	B-D	<i>Modeling Reliability, Peer Modeling Rubric</i>
3	20 min		CONSIDER A REAL ENERGY STORAGE SYSTEM Describe the Moss Landing Energy Storage Facility. Calculate how much energy was needed to fill the gap in Texas in February 2021.	E-I	<i>Electricity Production</i>
4	3 min		NAVIGATE: PEER FEEDBACK SELF-ASSESSMENT Reflect on giving and receiving feedback with a self-assessment exit ticket.	J	<i>Peer Feedback Self-Assessment</i>
<i>End of day 1</i>					
5	6 min		NAVIGATE Have students share some of their strategies to calculate the number of Moss Landings needed to provide enough energy to prevent an energy crisis in Texas. Carry out the calculation with the class.	K-L	whiteboard (optional), black markers (optional), calculator
6	20 min		CARRY OUT ADDITIONAL CALCULATIONS Calculate the cost of the energy storage system in partners, and as a class.	M	whiteboard (optional), black markers (optional), calculator
7	16 min		EVALUATE ADDITIONAL ENERGY STORAGE SOLUTIONS Raise the issue of challenges to battery installation. Give students 12 minutes to complete <i>Testing Battery Storage Solutions</i> . Have them finish this handout as home learning if time is short.	N-P	<i>Testing Battery Storage Solutions</i> , calculator
8	3 min		NAVIGATE Consider tradeoffs associated with batteries to motivate the home learning reading assignment.	Q-R	<i>Battery Construction Impacts, Engineering Design Tracker</i>
<i>End of day 2</i>					

Lesson 9 • Materials List

	per student	per group	per class
Lesson materials	• <i>Modeling Reliability</i> • <i>Peer Modeling Rubric</i> • science notebook • <i>Electricity Production</i> • <i>Peer Feedback Self-Assessment</i> • <i>Testing Battery Storage Solutions</i> • calculator • <i>Battery Construction Impacts</i> • <i>Engineering Design Tracker</i>	• whiteboard (optional) • black markers (optional) • calculator	

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Lesson 9 • Where We Are Going and NOT Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS3.B.1: Conservation of Energy and Energy Transfer.** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)
- **PS3.B.4: Conservation of Energy and Energy Transfer.** The availability of energy limits what can occur in any system. (HS-PS3-1)
- **PS3.D.1: Energy in Chemical Processes and Everyday Life.** Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)
- **ETS1.B.1: Developing Possible Solutions.** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

Students will evaluate various energy storage solutions by calculating their costs based on their energy storage capabilities. These calculations will help students consider more complex design solutions and their associated tradeoffs in the next lessons.

Students will encounter or co-develop definitions for the following words in this lesson: *storage solution, pumped hydropower, flywheel*. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

LEARNING PLAN for LESSON 9

1 · NAVIGATE

2 min

MATERIALS: None

Reflect on the prior day's learning. Present **slide A**. Say, *In our last class, we used Electric City to consider some of the decisions that power companies had to make to balance supply and demand. What are some solutions that might have allowed power companies to dispatch power without needing to rely on working power plants, and thus avoid needing to make inequitable tradeoffs?*

Listen for students to suggest adding batteries to the electric grid.

2 · INTEGRATE A BATTERY INTO THE ENERGY TRANSFER MODEL

20 min

MATERIALS: *Modeling Reliability*, *Peer Modeling Rubric*

Represent a reliable system using an energy transfer model. Say, *Let's consider how batteries would allow power companies to dispatch energy at moments when the energy supply drops. Throughout this unit, we have focused on energy flowing through the system, but we have not considered how a design solution could actually store energy, and how this could make an electric system more reliable during an energy crisis. Let's use our energy transfer model to represent this.*

Present **slide B** and distribute *Modeling Reliability* to each student. Instruct them to follow the guidelines in the handout to complete two models to show how adding a battery to a system affects its reliability. Give them 8 minutes for this task.

ADDITIONAL GUIDANCE	
	Keep in mind that these models represent a process (stability of an electric system when the energy supply drops) rather than a thing (a battery). Having two conditions to compare (before and after the energy supply drops) will yield a much richer snapshot of how students are thinking about energy transfer and reliability, two ideas that we have explored throughout this unit.

*** SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS**

In middle school, students had practice developing and revising models to show the relationships among a system's variables. In this unit, students will extend that practice by using models to *predict* the relationships between systems. Use this as an opportunity to discuss two of the goals of developing models in science: to make predictions about the behavior of a system, and to make our ideas visible to others.

Compare models with a partner and give feedback. Present **slide C** and distribute *Peer Modeling Rubric* to each student. Ask students to switch models with a partner, and give them 5 minutes to give feedback directly on their peer's model. Then give them a couple more minutes to revise their own model based on the feedback they received. *

Discuss energy transfer models. Present **slide D**. Lead a discussion using the slide prompts, as shown in the table below. *

Getting students to revise their models can be a challenge if they think the expectation with modeling is to show a "right" answer. Similarly to Lesson 3, ask students to develop their models using pencil, to make it easier to add or erase ideas.

*** SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS**

Models are generative tools for identifying a gap in our understanding. Identifying the limitations of a model is usually a good opportunity to discuss new questions about the behavior of a system that we cannot explain with our current ideas.

Suggested prompt	Sample student response
How did your models help you explain why adding batteries to our system makes it more reliable?	When the energy supply dropped, the battery provided the energy to the rest of the system. There was not a gap between energy supply and demand.
What limitations of your models made it harder to show or think about the role of the battery?	We did not know how much energy a battery can store. We did not have data about energy supply and demand, so we made some assumptions.

Suggested prompt	Sample student response
What new questions do we have?	What type of batteries are used in electric grids? How much energy can a large battery store? How do batteries work?



Collect *Modeling Reliability* at the end of this discussion. *

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Use *Modeling Reliability Key* to [assess students' modeling to predict stability in the distribution of electric energy when batteries are present and absent from the system.](#) (SEP: 2.3; DCI: PS3.B.1, PS3.B.4; CCC: 7.4)

What to do: Encourage students to use pencil to complete the first draft of their models. This will facilitate adding new ideas or changing them based on the feedback they receive.

Before students begin, you may want to remind them of the conventions the class has established to represent energy transfer or the components of the system.

Some students might be afraid that their ideas are wrong and feel constrained from representing them on paper. Assure these students that the goal of this task is to represent how they think about energy storage, and given that this is the first time we are exploring these ideas with our energy transfer conventions, the models are supposed to change over time from our discussions and investigations.

Building toward: [9.A Develop an energy transfer model to predict the stability in the distribution of electric energy when batteries are present and absent from the system.](#) (SEP: 2.3; DCI: PS3.B.1, PS3.B.4; CCC: 7.4)

Evidence that suggests students are starting to grasp the usefulness of models as generative tools includes the spontaneous use of models to support their own thinking. You might hear students raising new questions, revising an idea, or making predictions when using models to move their thinking forward.

* SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

An advantage of the energy transfer model is that it allows students to draw connections between energy flow and energy conservation. By using quantitative thinking to illustrate the amount of energy that flows across the different systems, the energy that is lost to the surroundings, and the matter interactions behind the flow of energy, students can make sense of reliability and energy conservation through a mechanistic lens.

Use this energy transfer model to elicit student ideas about interactions in the system and energy flow. Use prompts such as: *How do we know there is energy in the system? Does all the energy transfer from this component to the next? Where does the energy go?*

3 · CONSIDER A REAL ENERGY STORAGE SYSTEM

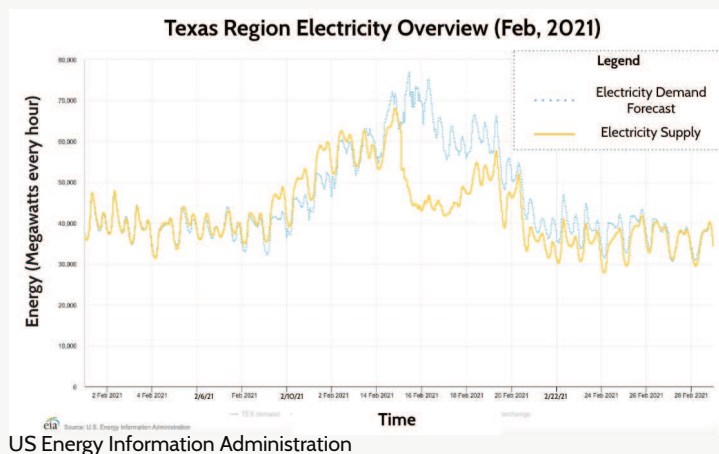
20 min

MATERIALS: science notebook, *Electricity Production*

Introduce an energy storage system. Present [slide E](#). Describe the Moss Landing Energy Storage Facility using the information presented in the slide. Then use the prompts to motivate the need to look at Texas energy supply and demand data, as shown in the table below.

Suggested prompt	Sample student response
How many facilities like this one would engineers need to add to the Texas grid to prevent a situation like what happened in February 2021?	A lot probably, but we don't have information to calculate this.
What do we need to know to figure this out?	We need to know how much energy was needed and how much energy was supplied.

Motivate looking at supply and demand again.



Present **slide F**. Ask, *What data do we have that could help us figure out how much energy was needed to fill the gap in February 2021?* Look for students to mention the graph of energy supply and demand we used in Lesson 3 (*Electricity Production*).

Say, *We have seen this data before. Let's see whether it can help us get new ideas to answer this question.*

Present **slide G**. Ask, *How can we figure out how much stored energy would have been needed to fill this gap?* Listen for students to suggest calculating the energy that was needed (demand) and subtracting the energy that was available (supply). It is OK if they don't come up with any ideas.

Calculate the energy needed to fill the gap between supply and demand. Present **slide H**. Say, *Let's look at what this graph is showing us. If we zoom in, we can see that each line is made of dots. Each dot represents the energy demand or supply at a given hour.*

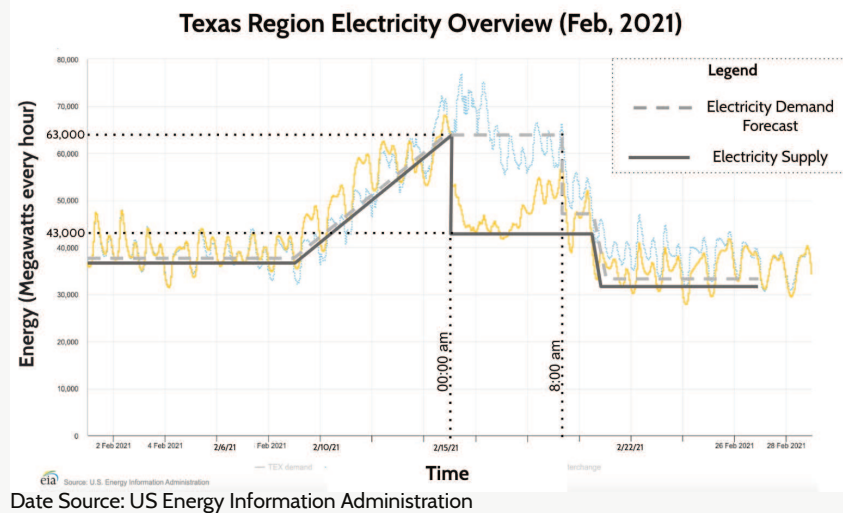
Point to the example on the slide and say, *This gap tells us how much stored energy was needed right then, in that hour. How can we figure out the energy needed for 1 hour?* Accept all responses.

Calculate the energy needed to fill a gap of an hour using the example in the slide: $63,000 \text{ MWh} - 43,000 \text{ MWh} = 20,000 \text{ MWh}$.

Continue, *OK, this was the energy needed for this particular hour. What could we do to figure out how much energy would be needed to fill this whole gap, so nobody ever ran out of power?* Indicate the area inside the large gap. Listen for students to suggest calculating the gap for each hour within that gap.

Say, *We could add up all the energy needed for each hour across this whole section, but that would take a lot of time. Let's do it the "quick and dirty" way. Let's just take an average gap--not the largest, not the shortest--to get an estimate, and then multiply it by the total number of hours in the whole section.*

Use area to approximate the energy in the gap. Return to **slide G** to scaffold this calculation. Draw a rectangle similar to the one in the image below. Say that the height of the rectangle (amount of energy) is the same as the average gap on the graph, which is around 20,000 MWh, and that the number of hours in the whole gap is approximately 100. Calculate the area using these values: $20,000 \text{ MWh} \times 100 \text{ h} = 2,000,000 \text{ MWh}$.



Revise our units. Present slide I. Ask, *How do we know that the area of the shape between supply and demand will tell us how much energy was missing?* Highlight the units of the x- and y-axes, and work with the class to cross out variables from the numerator and denominator in the calculation.

4 · NAVIGATE: PEER FEEDBACK SELF-ASSESSMENT

3 min

MATERIALS: *Peer Feedback Self-Assessment*

Assign Peer-Feedback Self-Assessment as an exit ticket. Present slide J and say, *It can be hard to give and receive feedback. Spend these last few minutes reflecting on how you did today with giving and receiving feedback using Peer Feedback Self-Assessment.* Distribute *Peer Feedback Self-Assessment* to each student, and collect their completed exit ticket as they leave.

End of day 1

5 · NAVIGATE

6 min

MATERIALS: whiteboard (optional), black markers (optional), calculator

Reorient to the problem we are trying to address. Present slide K. Describe the problem we were trying to solve in the last class period. Ask students to share some of their ideas about how to calculate the number of Moss Landings needed to provide enough energy to prevent an energy crisis in Texas. You can ask students to do their calculation on a whiteboard (if they have them) and hold it up.

Carry out the calculation with the class, describing how to do it:

$$2,000,000 \text{ MWh} * \frac{1 \text{ system}}{1,600 \text{ MWh}} = 1,250 \text{ systems}$$

Motivate calculating area and cost. Present slide L. Say, *1,560 Moss Landing systems seem like a lot. What other factors should we consider when deciding if we should build this large number of battery storage systems?* Listen for the following ideas:

- the space these devices will be in
- the cost
- the amount of resources needed to build them
- the time needed to build them
- the environmental impact of building all these batteries

Say, *Let's calculate some of these factors!*

6 · CARRY OUT ADDITIONAL CALCULATIONS

20 min

MATERIALS: whiteboard (optional), black markers (optional), calculator

Calculate the cost of the design solution. Present slide M. Mention that building an energy storage facility like Moss Landing costs about 400 million dollars. Ask students to work in partners to use this information to calculate the answers to the slide's questions:

- *How much would it cost to build sufficient facilities to mitigate the Texas crisis?*
- *Texas has about 30 million residents. How much would it cost per person to install this solution?*

You can ask students to do their calculations on a whiteboard (if they have them), and have them hold up the whiteboard when you debrief the calculations.

$$\frac{400,000,000 \text{ dollars}}{1 \text{ system}} * 1,250 \text{ systems} = 500,000,000,000 \text{ dollars} = 500 \text{ billion dollars}$$

$$\frac{500,000,000,000 \text{ dollars}}{30,000,000 \text{ residents}} = 16,666 \text{ dollars/resident}$$

Debrief the calculations. Invite a volunteer to come to the front and write their procedure for solving the problem on the board. Scaffold this conversation with the following prompts:

- Who else used a similar approach?
- Who used a different strategy?

7 · EVALUATE ADDITIONAL ENERGY STORAGE SOLUTIONS

16 min

MATERIALS: *Testing Battery Storage Solutions*, calculator

Consider the challenges of adding batteries. Present slide N. Ask, *Based on our calculations, what are some of the challenges behind building enough batteries in Texas to make the system more reliable?* Listen for students to suggest that the costs are very high, and that not everyone would be able to pay for the cost of installing enough batteries in the system.



Present slide O. Ask students to apply the calculations we did in class to determine whether another energy storage solution might be more feasible for mitigating a crisis like the one in Texas. Distribute *Testing Battery Storage Solutions* to each student, and give them 12 minutes for this task. If that is not enough time, have them complete the handout as home learning, and collect it in the next class period (Lesson 10). You will use *Testing Battery Storage Solutions Key* to score *Testing Battery Storage Solutions*.

Discuss the feasibility of other solutions. Present slide P and give students a minute to turn and talk about the prompt: *Based on your calculations, which energy storage solution(s) might be more feasible for mitigating a crisis like the one in Texas?* Then invite students to share with the class. Ask them to use their calculations to support their answers.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Use the key to score the handout. Look for students to:

- Show units in their calculations, and the conversions they make for costs, efficiency, and land area of use. (SEP: 5.5)
- Support their claims about feasibility using their calculations. (SEP: 5.5; DCI: ETS1.B.1, PS3.D.1; CCC: 3.1)

What to do: Encourage students to solve the problems step by step. This might help them avoid technical errors and make sure to track the units that are eliminated along the solution. If they have difficulties deciding which design solution is more feasible, suggest they rank each solution for cost, land area of use, and efficiency, and then decide which one performs better overall.

This is an opportunity to identify students who will need additional support for the calculations in the final transfer task. Find time after class to work with them individually, so they feel more comfortable applying calculations to the problem. To help them visualize the problem, go back to our geometric representations about how many units are needed. Make sure to always talk about the calculations in the context of the problem we are trying to solve, to help students see the “why” of the math in addition to the “how.”

Building toward: 9.B Apply ratios, rates, percentages, and unit conversions to calculate the costs and land area of use of a design solution to evaluate its feasibility for preventing an energy crisis like the one in Texas in 2021. (SEP: 5.5; DCI: ETS1.B.1, PS3.D.1; CCC: 3.1)

8 · NAVIGATE

3 min

MATERIALS: *Battery Construction Impacts*, *Engineering Design Tracker*



Motivate the home learning reading. Present slide Q. Say, *We have a lot of ideas to support the addition of batteries as a design solution that can make our systems more reliable, but we have seen that all design solutions have tradeoffs associated with them. Ask, Can you think of any examples of costs that are not financial?* Accept all responses.

Present **slide R**. Say, *I have a reading that will give us more information about some of the additional costs involved in the production of batteries to make our systems more reliable.*

Distribute *Battery Construction Impacts* to each student. Ask them to use the ideas from the reading to update their *Engineering Design Tracker*. See *Engineering Design Tracker Examples* for an example of how the tracker might look at this point in the unit. Say, *We will use some of the ideas from the reason to talk about our communities next time, and what kinds of decisions we would like to advocate for.*

Additional Lesson 9 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

These are the CCMS-related ideas that are used to support sensemaking in this lesson.

Number and Quantity

- CCSS.MATH.CONTENT.HS.N-Q.2. **Quantities:** Define appropriate quantities for the purpose of descriptive modeling.
- CCSS.MATH.CONTENT.HS.N-Q.1. **Quantities:** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

Students continue using quantitative reasoning to consider how to model the role of a battery in the flow of energy in a system. This will support them in making connections between energy storage and reliability.

Students will also apply ratios and unit conversions to calculate the costs and land area of use of different energy storage systems.

LESSON 10: What decisions do we need to make to design more reliable systems to meet our community's energy needs?

PREVIOUS LESSON *We developed and revised energy transfer models to represent how batteries can make electric grid systems more reliable. We quantified how much energy was needed to prevent the energy crisis in Texas 2021. We used data from existing energy storage solutions to calculate the number of batteries needed and the costs associated with adding them. We wondered about the non-financial costs of design solutions.*

THIS LESSON

INVESTIGATION

3 days



Finetooth, CC BY-SA 3.0

We read about tradeoffs associated with various energy sources. We create a Consensus Decisions Matrix that represents the criteria we agree are important when making decisions. We read quotes from interested parties, and develop and carry out an interview protocol to capture the values of people in our community. We begin developing a plan for improving electricity infrastructure in our community.

NEXT LESSON

We will use a computational model to measure the success of our solutions against various criteria. We will describe our design solution to our classmates and use each other's feedback to refine our designs. We will celebrate our progress on the Driving Question Board. We will complete an assessment, explaining energy transfer in a solar sand power plant and using data to evaluate its feasibility for providing reliable power to a community.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

10.A Define the problem, and then interview various interested parties in our community to identify criteria that can help make decisions to improve the electricity infrastructure, including how it is designed for reliability (stability) and its social, cultural, and environmental impacts. (SEP: 1.4, 1.8; DCI: ETS1.B.1; CCC: 7.4)

10.B Analyze data generated by interviews with community members to specify criteria for success related to energy solutions, such as monetary cost, safety, and reliability, and weigh cost/benefit tradeoffs related to social, cultural, and environmental impacts. (SEP: 4.6; DCI: ETS1.B.1; CCC: Influence of Science, Engineering, and Technology on Society and the Natural World, Science Is a Human Endeavor)

WHAT STUDENTS WILL FIGURE OUT

- When developing solutions to redesign our electric grid, we need to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to weigh the various social, cultural, and environmental impacts that specific choices may have.
- Input from interested parties and people we know can help us decide which values and priorities should guide how we address tradeoffs in our local energy grid solution.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Have students turn and talk about criteria that might be missing from our decision matrices.	A	<i>Decisions Matrix</i> from Lesson 4
2	20 min		READ ARTICLES AND IDENTIFY TRADEOFFS IN JIGSAW GROUPS Assign each student an article about tradeoffs associated with the energy sources we have been investigating. Create jigsaw groups including at least three articles per group to identify additional important criteria and update students' decision matrices.	B–C	<i>Biomass Impacts, Coal Impacts, Gas Impacts, Wind Impacts, Solar Impacts, Hydropower Impacts, or Nuclear Impacts</i> , colored pencils
3	5 min		CONSIDER HOW COSTS AFFECT PEOPLE Elicit student ideas about costs that are not financial to motivate the need to develop criteria for making decisions about energy production.	D	
4	14 min		BUILD A CLASS CONSENSUS DECISIONS MATRIX Have students generate ideas for categories in a Scientists Circle. As a class, decide which criteria to include in a Consensus Decisions Matrix, and rate how well the various energy sources meet them.	E	<i>Decisions Matrix</i> and <i>Energy Source Cards</i> or https://docs.google.com/presentation/d/1tKTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282 from Lesson 4, Consensus Decisions Matrix poster, markers
5	3 min		NAVIGATE Have students record their personal rankings of the most important criteria. As an exit ticket, have them place stickers on the Consensus Decisions Matrix to reflect the most important categories for us to weight.	F–G	stickers, Consensus Decisions Matrix poster
End of day 1					
6	5 min		NAVIGATE: NOTICING PATTERNS Review the Consensus Decisions Matrix to identify the criteria that we felt were most important.	H	Consensus Decisions Matrix poster
7	20 min		CONSIDER THE VALUES OF INTERESTED PARTIES Motivate the reading about interested parties. Have students read and discuss the interested parties' quotes in pairs or small groups.	I–K	<i>Quotes from Interested Parties</i> , Consensus Decisions Matrix poster, Community Agreements poster
8	8 min		PREPARE TO INTERVIEW INTERESTED PARTIES Have students turn and talk about how to represent the values of interested parties before making decisions about energy.	L	
9	12 min		DEVELOP A SCRIPT FOR COLLECTING INTERESTED PARTIES' FEEDBACK Have students work in partners to develop a script for collecting interested parties' feedback. As a home learning assignment, students will use their script to interview an interested party.	M–N	<i>Interview Protocol</i>
End of day 2					

Part	Duration		Summary	Slide	Materials
10	10 min		NAVIGATE Have students debrief their interviews in small groups.	O	
11	5 min		ADD RANKINGS OF INTERESTED PARTIES TO THE CLASS MATRIX Have students add the rankings of the people they interviewed to the Consensus Decisions Matrix.	P	<i>Interview Protocol</i> , stickers, Consensus Decisions Matrix poster
12	8 min		DECIDE HOW TO WEIGHT CRITERIA Have students look for new patterns in the importance given to each criterion on the Consensus Decisions Matrix poster. Co-develop a system for weighting the criteria.	Q-R	Consensus Decisions Matrix poster
13	12 min		INTRODUCE THE DESIGN CHALLENGE Have student groups complete the first two tasks on the <i>Design Challenge</i> handout to prepare to develop a community plan.	S	<i>Design Challenge</i> , <i>Energy Source Statistics</i> , Consensus Decisions Matrix poster
14	10 min		NAVIGATE Give students the link to the copy of https://docs.google.com/forms/d/1Xp-dPusvOa59-ZFiyI03ghf7j6rOHdNzQqGfRBsnjU4/copy to complete the Electronic Exit Ticket.	T	computer with access to the copy of https://docs.google.com/forms/d/1Xp-dPusvOa59-ZFiyI03ghf7j6rOHdNzQqGfRBsnjU4/copy

End of day 3

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Decisions Matrix</i> from Lesson 4 <i>Biomass Impacts</i> <i>Coal Impacts</i> <i>Gas Impacts</i> <i>Wind Impacts</i> <i>Solar Impacts</i> <i>Hydropower Impacts</i> - or <i>Nuclear Impacts</i> - colored pencils <i>Decisions Matrix</i> and <i>Energy Source Cards</i> or https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282 from Lesson 4 - stickers <i>Interview Protocol</i> <i>Design Challenge</i> - computer with access to the copy of https://docs.google.com/forms/d/1Xp-dPusvOa59-ZFiyI03ghf7j6rOHdNzQqGfRBsnjU4/copy	<i>Quotes from Interested Parties</i> <i>Energy Source Statistics</i>	- Consensus Decisions Matrix poster - markers - Community Agreements poster

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Prepare chart paper for Consensus Decisions Matrix poster.

Spin off a copy of <https://docs.google.com/forms/d/1Xp-dPusvOa59-ZFiyI03ghf7j6rOHdNzQqGfRBsnjU4/copy>, but don't share it until the end of day 3, for the Electronic Exit Ticket.

Lesson 10 • Where We Are Going and NOT Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ETS1.B.1: Developing Possible Solutions.** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)
- **PS3.D.2** Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. (secondary to HS-PS4-5)

Ideas related to PS3.D.2 are introduced in a reading, but is not assessed, and is thus not associated with a lesson-level performance expectation (LLPE).

Note that one of the LLPEs associated with this lesson does not include a cross-cutting concept (CCC). While it is rare for OpenSciEd to not include a CCC as part of an LLPE, it is aligned with the ETS performance expectation that we are building toward in this unit (HS-ETS1-3), which lists the following “Connections to Engineering, Technology, and Applications of Science” statements as a third dimension of the performance:

- **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. (HS-ETS1-1) (HS-ETS1-3)
- **Science Is a Human Endeavor.** Science and engineering are influenced by society and society is influenced by science and engineering. (HS-ETS1-3)

There is no single correct way for students to prioritize the criteria, tradeoffs, and costs that will guide their design plans for improving electricity infrastructure in their community. What is important is that they recognize the need for expanding the range of voices that can help inform societal decisions, and that they use those voices to guide their plans.

Students will encounter or co-develop or encounter definitions for the following words in this lesson: *cost, benefit, interested party, life-cycle analysis, dispatchability*. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

LEARNING PLAN for LESSON 10

1 · NAVIGATE

3 min

MATERIALS: science notebook, *Decisions Matrix* from Lesson 4

Turn and talk about missing criteria. Remind students that we want to be able to advocate for decisions in the future of our own communities. Present **slide A**. Ask students to get out their science notebook and turn to their *Decisions Matrix* for reference. Have students turn and talk about the prompt: *After learning about batteries, and the costs of building some of them, what additional criteria might be missing from our decisions matrices?* Students may say cost, the environment, or social factors.

2 · READ ARTICLES AND IDENTIFY TRADEOFFS IN JIGSAW GROUPS

20 min

MATERIALS: *Biomass Impacts*, *Coal Impacts*, *Gas Impacts*, *Wind Impacts*, *Solar Impacts*, *Hydropower Impacts*, or *Nuclear Impacts*, science notebook, colored pencils

Read articles about tradeoffs with energy sources. Present **slide B**. Say, *When we investigated batteries, we noticed that the use of technology often has unintended impacts, which we need to take into account. It sounds like we might be missing some criteria related to the impacts of producing energy on people and the environment.*

Distribute one of the following articles to each student, either by randomly arranging students into 7 groups, or by purposefully assigning articles based on reading difficulty. *

- *Biomass Impacts*
- *Coal Impacts*
- *Gas Impacts*
- *Wind Impacts*
- *Solar Impacts*
- *Hydropower Impacts*
- *Nuclear Impacts*

Tell students that as they read their article, they should underline the benefits of each source of energy in one color and the costs in another color. Give them about 8 minutes to read. The articles are short, but if students do not get to the last page, that is fine.

When they are finished reading, they need to choose a cost and a benefit to articulate a tradeoff using this sentence frame: *When choosing whether to use this source to produce electrical energy, there is a tradeoff between _____ and _____.* Ask them to write this frame in their science notebook.

Discuss tradeoffs in jigsaw groups. Assign students to jigsaw groups representing at least three articles in each, and present **slide C**. Instruct students to share their tradeoffs one by one in their groups, and look for themes that will help identify additional important criteria. Then ask them to decide together on at least one additional criterion to add to their *Decisions Matrix*.

As you move between groups to listen, you may hear a lot of ideas related to environmental impact. Students may articulate general criteria, such as “low environmental impact,” or something more specific, such as “low carbon emissions.” Some other possible criteria include “low cost” and “not dangerous to humans.” Give students about 10 minutes to work on this.

* ATTENDING TO EQUITY

At your discretion, either count students into random groups 1-7, or assign them into intentional, mixed-ability reading groups. The articles *Biomass Impacts*, *Gas Impacts*, and *Wind Impacts* are similar in reading level, but are shorter and therefore most accessible. *Hydropower Impacts* and *Nuclear Impacts* are most challenging due to potentially less-familiar vocabulary and content.

3 · CONSIDER HOW COSTS AFFECT PEOPLE

5 min

MATERIALS: None

Elicit student ideas about non-financial costs. Present **slide D**. Remind students that we (as a class) have not always agreed on what are the most important factors to consider. The costs and benefits of energy production are complicated and difficult to quantify in terms of simple ratios, because the costs aren't always financial, and some costs and benefits affect people differently. Read the slide's prompts aloud and elicit 1-2 ideas about each question, as shown in the table below.

Suggested prompt	Sample student response
<i>What are some examples of costs that are not financial?</i>	Harm to the environment or people.
<i>What are some examples of costs that affect some people differently than others?</i>	Some people might live closer to a coal power plant and experience more pollution, or they might live on the coast and be impacted by the sea level rising.
<i>What are some examples of benefits that affect some people differently than others?</i>	Some people might own an oil company, or live in a sunnier area.

Say, It sounds like these costs and benefits are complex, and vary based on who is being affected. Let's see whether we can agree on 5-8 top criteria that we want to consider when making decisions about energy.

4 · BUILD A CLASS CONSENSUS DECISIONS MATRIX

14 min

MATERIALS: science notebook, *Decisions Matrix* and *Energy Source Cards* or https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282 from Lesson 4, Consensus Decisions Matrix poster, markers

Create a Consensus Decisions Matrix. Present **slide E**. Ask students to bring their decision matrices to a Scientists Circle, then draw their attention to the matrix poster you prepared. Use a round-robin format to elicit ideas for categories by asking a student to suggest a new criterion, then asking the next student to suggest another, or to skip if all their categories have already been suggested, and so forth. Give space after each suggestion for disagreement by asking, *Do we agree that ideally an energy source will match this criterion?* Record the agreed-upon criteria on the poster during this discussion.

Remind students that it is fine if our matrix contains tradeoffs (e.g., highly reliable vs. highly renewable), but that we will have to find a way to compromise at some point. If students suggest a consideration without suggesting qualitatively whether we want its importance to be high, low, none, and so forth, remind them that we need something to aim for if this is going to be a criterion, rather than just a characteristic of the energy source.

Add ratings to the matrix. Suggest that we use a 3-star system to indicate how well a source matches that criterion. Move through the boxes quickly, again going around the Scientists Circle to ask students how they feel each energy source performs in each category, and record their responses on the poster. Encourage students to look back at their own matrices, as well as the *Energy Source Cards* or https://docs.google.com/presentation/d/1tKTTmLYxgirSgziBWlzYyDY7UJhiCPXfldhn7d11Kyc/edit#slide=id.g23f5fc8198b_O_282 and their *Progress Trackers* to justify their suggestions.

5 · NAVIGATE

3 min

MATERIALS: science notebook, stickers, Consensus Decisions Matrix poster

Reflect on personal rankings of criteria. Present **slide F**. Ask students to stop and jot in their notebooks about what they think are the most important criteria for us to weight, and why.

Rank criteria on the poster with stickers. Present **slide G**. As an exit ticket, invite students to place stickers on the top of the Consensus Decisions Matrix to reflect their ranking, as described on the slide.

End of day 1

6 · NAVIGATE: NOTICING PATTERNS

5 min

MATERIALS: Consensus Decisions Matrix poster

Look back at the Consensus Decisions Matrix. Present **slide H**. Remind students of the matrix we built together during the last class. Use the slide's first prompt to get them looking for patterns in the way we placed our stickers on the poster. Every class will have different patterns. Help students see which categories their class felt were more important, and which categories there may have been disagreement on.

Consider where people may not agree. Read the slide's second prompt aloud: *Do you think that community members always agree about which criteria are the most important?* Listen for students to say probably not.

7 · CONSIDER THE VALUES OF INTERESTED PARTIES

20 min

MATERIALS: *Quotes from Interested Parties*, Consensus Decisions Matrix poster, Community Agreements poster

Link the reading to our Community Agreements. Present **slide I**. Motivate the reading about interested parties by telling students you have some quotes that can give us a glimpse into how various people approach a design solution with their own values. Then read the slide's prompt aloud: *These quotes come from real people. How can we rely on our Community Agreements to make sure we are treating their ideas with respect?* Listen for students to have ideas about considering the perspectives of others, speaking respectfully, and so forth.

Read and discuss the quotes. Present **slide J**. Arrange students in pairs or new small groups and distribute the *Quotes from Interested Parties* handout to each pair or group. Have students take turns reading each quote aloud in their pair or group, pausing after each to briefly discuss these questions:

- What does this person value when it comes to making decisions about the energy grid? How can you tell?
- Which columns of our Consensus Decisions Matrix would this person say were most important? Why?
- What design solutions would this person say were least important? Why?

Give students about 10 minutes to talk about these quotes.

ADDITIONAL GUIDANCE

This unit uses the term “interested parties” instead of “stakeholders.” Many governments, businesses, nonprofits, and other organizations are making this switch for a variety of reasons related to the latter term’s historical associations with power and even oppression.

1. The term *stakeholder* implies all parties have equal interests or rights in a decision, which is rarely the case.
2. The term is considered offensive by some Indigenous peoples, because it was historically used to divide and take land that they did not consider anyone’s to own. The “stake” portion originally referred to a literal stake in the ground, used to indicate ownership.
3. The term is narrow, because it was historically used to refer to only some people’s interests, particularly those who had financial ownership, rather than everyone affected by a decision.
4. The term implies differentials in who has knowledge and power in a situation.

For more information, visit some of the following resources:

- Sharfstein, J. M. (2016). Banishing “stakeholders”. *The Milbank Quarterly*, 94(3), 476.
- Hillerdal, C., Karlström, A., & Ojala, C. G. (2017). *Archaeologies of Us and Them*. Debating history, heritage and indigeneity.

Debrief the quotes. Present slide K and read the prompts aloud to to elicit student responses:

- *How did the lives and values of the people quoted inform the way they thought about energy decision-making?* Accept all ideas.
- *What are some other opinions about energy that you think were missing from the quotes?* Accept all ideas.

8 · PREPARE TO INTERVIEW INTERESTED PARTIES

8 min

MATERIALS: None

Turn and talk about representing interested parties. Present slide L and read the prompt aloud: *What could we do to make sure we are representing the interests of people in our community before we make decisions for our design project?* Have students talk to a partner about representing the values of interested parties.

Walk around the classroom and listen in. Then bring the class back together and say, *I heard a couple of suggestions about asking interested parties what criteria they value, and taking that into account. Let’s explore that idea.*

9 • DEVELOP A SCRIPT FOR COLLECTING INTERESTED PARTIES' FEEDBACK

12 min

MATERIALS: *Interview Protocol*

Consider the context we want to share with interested parties. Present slide M and read the prompt aloud: *If we were to go out and interview people about what criteria they value, what context do we need to share with them first?* Listen for ideas about what decisions we are trying to make, why those decisions are important, and so forth.



Work in partners on a script for collecting feedback. Present slide N. Distribute the *Interview Protocol* handout to each student. Have them work in partners to develop an interview script by completing Part 1 on the handout, which asks them to include the following and provides short descriptions of each:

- What we are trying to do
- Why we think these decisions are important
- Why we need their input



Use completed scripts for home learning. Give students the rest of the class period to work on developing their scripts in partners. * Make sure they have time near the end of class to preview the rest of the *Interview Protocol* handout and ask questions before they go home to interview interested parties. * **Do not** require that students complete this home learning, and **do not** score it; the goal is to promote conversation between students and others in their family and/or community about their values and decision-making.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- A clear definition of the problem we are trying to solve (designing a more reliable electric grid system that satisfies various criteria for success and the values of various interested parties) that can help interviewees understand the value of their input. (SEP: 1.4, 1.8; DCI: ETS1.B.1; CCC: 7.4)
- Questions intended to identify or clarify which criteria are most important to interested parties. (SEP: 1.4; DCI: ETS1.B.1)

What to do: Suggest students use the script they are developing to do a mock interview with a peer. This will help them refine their protocol and gain experience with interviewing.

Building toward: 10.A Define the problem, and then ask questions of various interested parties in our community to identify criteria that can help make decisions to improve the electricity infrastructure, including how it is designed for reliability (stability) and its social, cultural, and environmental impacts. (SEP: 1.4, 1.8; DCI: ETS1.B.1; CCC: 7.4)

SAFETY PRECAUTIONS



Emphasize to students that the interview should be conducted with someone they know, and that it does not need to be conducted in person; it can be done by phone or other electronic means. If they wish, students can interview another teacher, a friend from another class, or a friend in this class. If need be, help them connect with a teacher or administrator they feel safe talking to.

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Circulate among the groups to support students as they work on their protocols. Focus on the types of questions they generate. If the opportunity arises, model how to turn a question from a closed question answered with a “yes” or “no” to an open question that could elicit richer information from the interviewee. For example, a closed question might be: “Do you care about the environment?” That could be modified to an open-ended question, such as: “What environmental impacts related to energy generation are you more concerned about?”

* ATTENDING TO EQUITY

Universal Design for Learning: Framing students’ families and communities as legitimate funds of knowledge can serve multiple purposes: (1) help students feel that they belong in the science classroom by situating their family and community knowledge as productive resources for science; (2) engage students’ families in conversations about what is happening in the classroom; and (3) help students make connections between the science classroom and their everyday lives. This provides students access by supporting their engagement.

End of day 2

10 · NAVIGATE

10 min

MATERIALS: None

Debrief the interviews. Present slide O. Arrange students in small groups of 3-4 and discuss the prompts on the slide:

- *What can you infer from your interested parties' reasoning about what they value the most? What did they say that made you think that?*
- *How were those values reflected in their rankings?*
- *Did you notice your interested parties making tradeoffs, or compromises between criteria, informed by their values?*

11 · ADD RANKINGS OF INTERESTED PARTIES TO THE CLASS MATRIX

5 min

MATERIALS: Interview Protocol, stickers, Consensus Decisions Matrix poster

Add rankings of interested parties to the class matrix. Present slide P. Ask students to come to the front of the classroom and use stickers to add the rankings of the people they interviewed to the Consensus Decisions Matrix poster, using the same color-coding as they did with their own rankings.

12 · DECIDE HOW TO WEIGHT CRITERIA

8 min

MATERIALS: Consensus Decisions Matrix poster

Look for new patterns in the class matrix. Present slide Q and read its first question aloud: *What patterns do we notice now?* The answer will vary from class to class, but it is likely that some categories will now be clearer while others will still show disagreement. Tell students that engineers often face these difficult decisions, even after interviewing interested parties.

Motivate weighting the matrix. Pose the slide's second question: *How can we make sure that the criteria we believe are the "most important" count more than the others?* Revoice students' ideas about weighting, or counting certain categories more than others.

Co-develop a system to weight reliability as an example. Present slide R. Say, *One way engineers incorporate values into their decision-making is by weighting criteria. We can do this by multiplying our rankings, by adding additional stars, or by highlighting the rows we think are important.* Suggest that we start with the criterion of reliability. Ask students for ideas of how to weight this criterion, and then quickly come to consensus on a method that works. We recommend adding a "multiplier" of either 2 or 3 to indicate how important reliability is. *

* ATTENDING TO EQUITY

Building classroom culture: This is an important opportunity to emphasize that each individual has contributions to make to their community of learners. It is through differences in thinking that the class will grow their knowledge together.

13 · INTRODUCE THE DESIGN CHALLENGE

12 min

MATERIALS: Design Challenge, Energy Source Statistics, Consensus Decisions Matrix poster

Prepare to develop a community plan in small groups. Present slide S and distribute the *Design Challenge* handout to each student. Then arrange students into purposeful groups of 3-4. These groups will work together for several days on the culminating project, so make sure each group represents a diversity of ability.

Ask students to complete the first two tasks on the handout as part of the challenge:

- *Decide how and to what extent you will weigh interested parties' opinions to address tradeoffs.*
- *Use the Consensus Decisions Matrix and the Energy Source Statistics to identify and articulate specific criteria that will tell us whether the solution is successful.*

Point out the data in *Energy Source Statistics*. These data will be useful for helping students articulate quantitative criteria. Move around the classroom as students work, and support them in articulating their criteria, using numbers whenever possible.

MATERIALS: computer with access to the copy of <https://docs.google.com/forms/d/1Xp-dPusvOa59-ZFiyl03ghf7j6r0HdNzQqGfRBsnjU4/copy>

Navigate. Present slide T. Tell students that for our next class, you will bring in a new tool to help us determine what we need to do to meet our criteria to develop our community plan.

 **Assign the electronic Exit Ticket.** Give students the link to the copy of <https://docs.google.com/forms/d/1Xp-dPusvOa59-ZFiyl03ghf7j6r0HdNzQqGfRBsnjU4/copy> that you made before class (do not share the original link provided here with students, as that will create a new copy for each student, and you will not have access to their responses). Ask students to complete the electronic Exit Ticket on their own.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

Use the *L10 Electronic Exit Ticket Key* to assess student work in two dimensions.

What to do: Use the *L10 Electronic Exit Ticket Key* for strategies to support students in answering each of the questions in the Electronic Exit Ticket.

Building toward: 10.B Analyze data generated by interviews with community members to specify criteria for success related to energy solutions, such as monetary cost, safety, and reliability, and to weigh cost/benefit tradeoffs related to social, cultural, and environmental impacts. (SEP: 4.6; DCI: ETS.1.B.1; CCC: Influence of Science, Engineering, and Technology on Society and the Natural World, Science Is a Human Endeavor)

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

This lesson targets a Common Core ELA standard from the category of **Integration of Knowledge and Ideas**.

- **CCSS.ELA-Literacy.RST.11-12.9.** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Students need to weigh the values and priorities from the various interested parties they interviewed to decide the ranking of the criteria in the Consensus Decisions Matrix, resolving conflicting priorities when possible.

LESSON 11: What have we figured out, and what can we carry forward?

PREVIOUS LESSON

We read about tradeoffs associated with various energy sources. We created a Consensus Decisions Matrix that represented the criteria we agreed were important when making decisions. We developed and carried out an interview protocol to capture the values of people in our community. We began developing a plan for improving electricity infrastructure in our community.

THIS LESSON

PUTTING PIECES TOGETHER

3 days



We learn about the Energy Grid Calculator, a computational model we use to measure the success of our solutions against a variety of criteria. We describe our design solution to our classmates, and we give each other feedback that we use to refine our designs. We return to the Driving Question Board and celebrate our progress in light of all the questions we can answer. We work through an assessment task in which we explain energy transfer in a solar sand power plant and use data to evaluate the feasibility of using this technology to provide reliable power to a community.

NEXT LESSON

There is no next lesson.

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2,
HS-PS3-3, HS-ESS3-2, HS-ETS1-3,
HS-ETS1-4



WHAT STUDENTS WILL DO

11.A Define a problem related to the challenge of improving our electrical grid, and then design, evaluate, and refine a solution, taking into account social, cultural, and environmental impacts (both intentional and unintentional), based on results from a computational model, scientific knowledge we have figured out over the unit, weighted criteria, and tradeoff considerations. (SEP: 1.8, 2.6, 6.5, DCI: ETS1.A.2, ETS1.B.2, ESS3.A.2; CCC: 1.3)

11.B Ask questions to identify and refine criteria for success for our design solutions, including reliability (stability) and social, cultural, and environmental impacts. (SEP: 1.4, DCI: ETS1.B.1; CCC: 7.4)

Transfer Task PE: 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 motions of particles (objects) and energy associated with the relative positions of particles (objects). (SEP: 2.3, 4.6, 5.5; DCI: PS3.A.1, PS3.A.2, PS3.A.4, PS3.B.1, PS3.B.4, PS3.D.1, ETS1.B.1; CCC: 5.2, 5.3)

WHAT STUDENTS WILL FIGURE OUT

- Solving the problems with our energy grid will require tough choices because all choices have tradeoffs.
- Factors that impact whether an energy grid solution is desirable include reliability, cost, carbon emissions, land use, and other factors.
- The best solution to the problem of how to improve our energy grid depends on lots of factors, including the values and personal priorities of different people and interested parties.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Reconvene the culminating project groups formed in Lesson 10, and have students discuss criteria and measures.	A	<i>Design Challenge</i>
2	10 min		INTRODUCE THE ENERGY GRID CALCULATOR Introduce the Energy Grid Calculator as a tool for measuring success against a number of possible criteria.	B	computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKjm4i_gl/copy
3	10 min		COMPLETE QUESTION 2 OF THE DESIGN CHALLENGE Have students complete Question 2 of the <i>Design Challenge</i> using the Energy Grid Calculator.	C	<i>Design Challenge</i> , computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKjm4i_gl/copy
4	4 min		INTRODUCE ADDITIONAL FUNCTIONS OF THE ENERGY GRID CALCULATOR Demonstrate how to use the Energy Grid Calculator as a tool for simulating grid solutions.	D	computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKjm4i_gl/copy
5	18 min		COMPLETE PART 2 OF THE DESIGN CHALLENGE Have students use the calculator to make changes to the grid that reflect their design criteria. Then instruct them to complete Q3 of the <i>Design Challenge</i> .	E-F	<i>Design Challenge</i> , computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKjm4i_gl/copy
End of day 1					
6	15 min		COMPLETE PART 3 OF THE DESIGN CHALLENGE Instruct students to complete Part 3. Circulate as they work to provide support.	G	<i>Design Challenge</i> , computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKjm4i_gl/copy
7	20 min		USE A STAYER-STAYER PROTOCOL TO SHARE IDEAS AND GIVE PEER FEEDBACK Describe the stayer-strayer protocol and how students will give peer feedback using the handout.	H	2 copies of <i>Peer Interactions Support</i>
8	10 min		INCORPORATE FEEDBACK INTO PRODUCTS Have students return to their original groups and process the feedback they received. Assign the home learning handout.	I-K	<i>Peer Feedback Self-Assessment</i> , 2 copies of <i>Peer Interactions Support</i> , Consensus Decisions Matrix poster (from Lesson 10)
End of day 2					
9	5 min		NAVIGATE: MAKING CONNECTIONS Use crosscutting concepts to review our progress over the course of this unit.	L	
10	20 min		RETURN TO THE DRIVING QUESTIONS BOARD Have students work in pairs to determine which questions the class has answered from the DQB. Discuss the questions the class can now answer, and celebrate how far we have come.	M-N	tape, <i>Reviewing Our DQB</i> , Driving Questions Board

Part	Duration		Summary	Slide	Materials
11	20 min		ADMINISTER THE FINAL TRANSFER TASK Set the context for the assessment and have students complete the assessment task in class.	O	<i>Sand and Mirrors Transfer Task</i> , calculator

End of day 3

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials	• <i>Design Challenge</i> • science notebook • <i>Peer Feedback Self-Assessment</i> • tape • <i>Sand and Mirrors Transfer Task</i> • calculator • science notebook.	• computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy • 2 copies of <i>Peer Interactions Support</i> • <i>Reviewing Our DQB</i>	• computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy • Consensus Decisions Matrix poster (from Lesson 10) • Driving Questions Board

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole punch all the images and handouts so they can be added to students' notebooks.

Before class, set up your own copy of https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy for your region by following the directions in <https://www.youtube.com/watch?v=Ye3PjOCERAc> or Steps 1-4 in the "Background Data" tab of the grid calculator. The copy you edit will be specific to your region, so you will need to input a few details, as shown in the video. Your region-specific copy should then be shared with your students so they have their own copy to work with. Do not permit students to edit your region-specific copy--they must work within their own copy.

You can review <https://youtu.be/taBlfiLTavw> in advance of class to see an example of how it can be introduced to students using Questions 1-4 in the "Current" tab. If students are absent on the day of its introduction, you can also give them this link as a way to get caught up on how to answer Questions 1-4.

Decide how you would like students to present their ideas. The lesson is written so that students create a product, but it does not include presentations. Consider planning at a future date for students to present their ideas in front of the class, a larger group of students, the interested parties they interviewed, or even some local energy experts, if you can arrange it.

On day 3, make sure the Driving Question Board is visible to everyone in the classroom.

Lesson 11 • Where We Are Going and NOT Going

This lesson is designed to coherently build and assess ideas related to the following disciplinary core ideas:

- **ETS1.B.1: Developing Possible Solutions.** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)
- **ETS1.B.2: Developing Possible Solutions.** Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)
- **ETS1.A.2: Defining and Delimiting Engineering Problems.** 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. (HS-ETS1-1)
- **ESS3.A.2: Natural Resources.** All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2)

This is a putting-the-pieces-together lesson for the entire unit, giving students the chance to evaluate where they have been, what resources they have collected, and how they can use those resources to make decisions. There is no single right way for students to make these decisions. What is important is that they know how to justify their decisions using a combination of engineering ideas about criteria, constraints, and tradeoffs, and science ideas about energy loss to the environment, factors that affect energy transfer, and the components and interactions involved in energy transfer in the electricity grid.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

3 min

MATERIALS: *Design Challenge*

Discuss criteria and measures in groups. Ask students to sit in the culminating project groups formed in Lesson 10. These should be the same groups they were in when they chose criteria on the *Design Challenge*. Present **slide A**. Pose the prompts on the slide and ask groups to discuss briefly:

- *What information did you use to identify and articulate specific criteria that will tell us if a solution is successful?*
- *What tools could we use to measure the success of a solution against these criteria?*

2 · INTRODUCE THE ENERGY GRID CALCULATOR

10 min

MATERIALS: computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gI/copy

Introduce the Energy Grid Calculator. Before class, make sure you set up the Energy Grid Calculator for your region by following the directions in <https://www.youtube.com/watch?v=Ye3PjOCERAc>.

Bring students' attention to the front of the room, and present **slide B**. Explain that you have a tool called the Energy Grid Calculator, which can help us measure the success of a solution against a variety of criteria, such as cost, reliability, dispatchability, capacity, power, or environmental impact.

Project the region-specific copy of https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gI/copy that you created before class at the front of the classroom, and make sure you are on the tab titled "Current". Begin by directing students' attention to the area statistics on the far right. Tell students that the data in this calculator are tailored for our region, and these are the statistics for our region. Then explain that they will not need to use this part of the calculator, and scroll back to the left.

Use the prompts in the tables below to move through key statistics and functions in the calculator. Move quickly through these prompts, as students will get a chance to play around on their own. If students are stumped about what something in the calculator means, do not play guess-what's-in-my-head. Explain and move on.

If using a teammate's copy, paste link here:

Current Grid Estimate		Maximum Energy Production	Maximum Supply After Wire Losses	Carbon Emitted per Person per year**	Local Land Use (non-forested)	Global Life Cycle Land Use
Reliability		2516 MW	2287 MW	4276 kg	24035 acres	72586 acres
"Winter Crisis" - What percent of demand can be met if there is a winter crisis like in Texas, '21?		Maximum Demand: 2287 MW	2287 MW	Current CO2	24.3% of City Area	73.3% of City Area
Wind		Wind & Solar: 26.3%				
"Windless Night" - For how many hours will ALL people have power if wind & solar drop to zero?						
unlimited hrs						

Values above show estimated **energy supply and demand**, and estimated impacts on **carbon & land use**.

Current Plants to Demolish or Keep:	Plant Quantity
Coal	Currently 1 (estimated)
Natural Gas	Currently 5 (estimated)
Petroleum	Currently 0 (estimated)
Nuclear	Currently 0 (estimated)
Biomass	Currently 0 (estimated)
Geothermal	Currently 0 (estimated)
Hydro	Currently 4 (estimated)
Wind	Currently 215 (estimated)
Solar PV	Currently 64 (estimated)
Energy Storage	(very rough estimate)

Winterized? (check for yes) ☒

Q1: For current estimates, what do you notice about **energy supply and demand**, **carbon emissions**, and **land use**?

Q2: What do you notice in the two reliability measures: "Winter Crisis" and "Windless Night"? Do these measures make sense with what you know about your state's grid?

Q3: What changes do you notice when you "demolish" a coal or gas plant, by reducing the yellow number?

Q4: How does winterization affect the reliability of your state's grid?

Texas didn't winterize completely because winter storms have been so infrequent.

Orient to the energy supply and demand measures. Begin by directing attention to the light blue table.

Suggested prompt	Sample student response
What do you notice about the Maximum Energy Production and Maximum Energy Supply?	They are different.
Why is less energy being supplied to the community than is being produced?	Energy loss in the system to the surroundings.
What about demand? What do you notice?	Supply equals demand, which we know is important.
What do you think this percentage here, Wind and Solar, represents?	What percentage of the power in our region is produced by wind and solar.
Why do you think it is important to keep track of how much energy is produced from wind and solar?	(Accept all ideas.)

Orient to the carbon measures. Next, direct attention to the light pink table.

Suggested prompt	Sample student response
What do you notice about the carbon emissions statistics?	It shows the kilograms of CO ₂ emitted per person per year.
What does it say about the type of energy sources that are part of this grid?	They emit a lot of CO ₂ . They might not be renewable.

Suggested prompt	Sample student response
<i>Do you think that red here is showing that the carbon emissions are very high, or very low? Why?</i>	Very high, because red is usually bad, and our criteria is for carbon emissions to be low.

Orient to the land use measures. Next, direct attention to the light yellow table.

Suggested prompt	Sample student response
<i>What do you notice about the land use statistics?</i>	One is local and one is global.
<i>Why would there be two different kinds of land use?</i>	One might be land to build the plant, and the other might be land to produce the fuel (i.e., grow the trees, mine the coal, frack the gas).

Orient to the reliability measures. Pose the second prompt on the calculator: *What do you notice in the two reliability measures, "Winter Crisis" and "Windless Night"?*

Suggested prompt	Sample student response
<i>What do you notice about these two measures of reliability?</i>	One is a percent and one is hours.
<i>What do you think they mean?</i>	One is the percent of demand that can be met during an energy crisis. It should be 100% for the system to be fully reliable. The other one shows how much time the system can supply the demand if there is no energy generation from wind and solar. The more hours the better.
<i>What do we think it means that they are green?</i>	That the system is reliable right now.

Demolish a fossil fuel power plant. Show students how to demolish a fossil fuel power plant in the calculator, and ask them what changes they notice.

Suggested prompt	Sample student response
<i>What changes do you notice when we "demolish" a coal or gas plant, by reducing the yellow number?</i> <i>Why do you think that is?</i>	The reliability goes down. The energy production goes down. The carbon emissions go down. There are some reds and oranges that were not there before. Because without that, the percentage of wind and solar goes up, and there is not enough storage for that. We still depend on fossil fuels for reliability.

ADDITIONAL GUIDANCE

If no coal plants are supplying power to your community's electric grid, demolish a power plant that you think will allow students to notice changes (or lack thereof) in reliability, carbon emissions, cost, and energy production.

Briefly consider winterization. Point out that some experts say that Texas didn't winterize completely before 2021 because winter storms have been so infrequent there. Then ask, *Do you think the grid is winterized where we live?* Students' responses will vary based on where your school is located. In a warm climate as in most of Florida, California, or Louisiana, students may say no, they don't think their grid is winterized. In a cold climate as in Colorado, Michigan, or Massachusetts, students will probably say yes.

Ask, *What do you think would happen to the reliability during a storm if a grid is not winterized?* Try unclicking the box at the bottom and see what happens. The reliability during a storm should drop significantly.

ALTERNATE ACTIVITY

We recommend demonstrating the Energy Grid Calculator live for the class so you can engage students in an interactive exploration of the tool. But if a student is absent, they can watch the orientation video for this tool, available at <https://youtu.be/taBlfiLTavw>.

Remind students that they can choose other criteria. Make sure to point out that the criteria listed in the calculator are not the only criteria they can measure success against. For example, if a group decides that the availability of coal mining jobs is one of the most important criteria for their community, they can still use this to design and justify their decisions.

3 · COMPLETE QUESTION 2 OF THE DESIGN CHALLENGE

10 min

MATERIALS: *Design Challenge*, computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9IvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy

 **Complete Question 2 of the challenge using the Energy Grid Calculator.** Present slide C. Send student groups to their copy of the https://docs.google.com/spreadsheets/d/1rS_a5lOyg9IvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy. Ask them to work on Q2 of the *handout*: *All forms of energy production and other resource extraction have associated costs and risks as well as benefits. Use evidence from our readings, data analysis, and the Energy Grid Calculator to make an argument for why our region's current grid solution has costs and risks associated with it, as well as benefits.*

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Use the *Design Challenge Key* for assessment support. (SEP: 1.8, 2.6, 6.5, CCC: 1.3; DCI: ETS1.A.2, ETS1.B.2)

What to do: Move around the room to support students as they work. Answer questions about the Energy Grid Calculator, and help students remember what other kinds of evidence they might have available from previous lessons.

Building toward: 11.A.1 Define a problem related to the challenge of improving our electrical grid, and then design, evaluate, and refine a solution, taking into account social, cultural, and environmental impacts (both intentional and unintentional), based on results from a computational model, scientific knowledge we have figured out over the unit, weighted criteria, and tradeoff considerations. (SEP: 1.8, 2.6, 6.5; DCI: ETS1.A.2, ETS1.B.2; CCC: 1.3)

4 · INTRODUCE ADDITIONAL FUNCTIONS OF THE ENERGY GRID CALCULATOR

4 min

MATERIALS: computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9IvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy

Demonstrate how to simulate solutions with the Energy Grid Calculator. Present slide D. Show students how to move to one of the "Solution" tabs in the calculator. Very quickly, enact each of the functions listed on the slide:

- Demolish power plants.
- Build new power plants.
- Choose to winterize, and where to build.
- Add wiring upgrades and energy storage solutions.

If you have time, you can show <https://youtu.be/k7xze0VeGAs> in class to outline the features of the Energy Grid Calculator, or give students the link to the video to watch themselves. Alternatively, there is a link to this video within the Energy Grid Calculator, which students can click if they are confused.

5 · COMPLETE PART 2 OF THE DESIGN CHALLENGE

18 min

MATERIALS: *Design Challenge*, computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9IvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy

Manipulate the Energy Grid Calculator to reflect criteria. Present **slide E**. Give students 10 minutes to use the “Solution” tab of the calculator to make changes to the grid that reflect the criteria they chose in Part 1, and see what happens. Move around the classroom and listen as they discuss the prompts on the slide:

- *How do your changes affect the measures at the top of the sheet?*
- *What does that mean?*



Complete Part 2 of the challenge. Present **slide F**. Direct students to start working on Q3 and Q4 of the handout:

- *The Energy Grid Calculator is a computational model that can be used to aid in the engineering design process. Refine an engineering solution in your copy of the Energy Grid Calculator to reflect the priorities of the interested parties you interviewed. Then summarize in words the changes you made to your region's current grid solution.*
- *In your Engineering Design Tracker, you have considered new science ideas and applied these ideas to suggest possible changes to our electric grid. Describe one or more ideas from the Engineering Design Tracker that your group used to inform your design choices. Use evidence from the Engineering Design Tracker or related sources to explain why you made these specific design choices. What are the costs and benefits of this choice? Why are these costs and benefits relevant to people and the planet?*

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Use the *Design Challenge Key* for assessment support. (SEP: 1.8, 2.6, 6.5, CCC: 1.3; DCI: ETS1.A.2, ETS1.B.2)

What to do: Move around the room to support students as they work. Use the *Design Challenge Key* for assessment support.

Building toward: 11.A.2 Define a problem related to the challenge of improving our electrical grid, and then design, evaluate, and refine a solution, taking into account social, cultural, and environmental impacts (both intentional and unintentional), based on results from a computational model, scientific knowledge we have figured out over the unit, weighted criteria, and tradeoff considerations. (SEP: 1.8, 2.6, 6.5; DCI: ETS1.A.2, ETS1.B.2; CCC: 1.3)

End of day 1

6 · COMPLETE PART 3 OF THE DESIGN CHALLENGE

15 min

MATERIALS: *Design Challenge*, computer with access to https://docs.google.com/spreadsheets/d/1rS_a5lOyg9lvPvEgCXOM-_EeOjOVT_K2VOFKJm4i_gl/copy

Complete Part 3 of the challenge. ✱ Present slide G. Read the prompt from Part 3 of the *Design Challenge* aloud, and make sure students understand the task:

- As a group, make a slide deck, poster, infographic, presentation, or video to communicate your plan. In your work, make sure to:
- Explain why our region's current grid solution has costs and risks associated with it, as well as benefits. (see Q2)
- Describe, in words and pictures or diagrams, the criteria you prioritized, then describe the changes you made to our region's current grid solution, and justify your choices by explaining the predicted impact those changes will have. (see Q3)
- Use a model to clearly demonstrate how your solution prioritizes reliability or other criteria. Use any model (or models) that you believe will be convincing to your audience. (see previous models)
- Include relevant science ideas from your *Engineering Design Tracker* that help explain your choices. (see Q4)

Move around the room to support students as they work. Use the *Design Challenge Key* for assessment support.

ADDITIONAL GUIDANCE

Consider planning at a future date for students to present their ideas in front of the class, a larger group of students, the interested parties they interviewed, or even some local energy experts, if you can arrange it.

✱ ATTENDING TO EQUITY

Universal Design for Learning: This project offers students the chance to *express* their ideas using a diverse set of modalities. This supports student ownership of their learning by giving them choice, access, and control in navigating their own understanding around the science ideas. Encourage students to choose a modality that works for their group.

7 · USE A STAYER-STAYER PROTOCOL TO SHARE IDEAS AND GIVE PEER FEEDBACK

20 min

MATERIALS: 2 copies of *Peer Interactions Support*

Invite two students from each group to “stay” while two students “stray.” Display slide H. Distribute two copies of the *Peer Interactions Support* handout to each group of four: one for the “stayers” and one for the “strayers.” Ask each group to nominate half of their group to be the first strayers. Stayers need to be ready to share their ideas about their design solution with the visiting strayers.

Explain that the strayers will spend 10 minutes visiting other groups before they come back and switch roles with the stayers. Tell students to use the prompts on the handout to guide their interactions while they participate in the activity.

Students will spend about 5 minutes each at two different groups before switching roles, for a total of 20 minutes. Use a timer to facilitate the logistics of this protocol.

8 · INCORPORATE FEEDBACK INTO PRODUCTS

10 min

MATERIALS: science notebook, *Peer Feedback Self-Assessment*, 2 copies of *Peer Interactions Support*, Consensus Decisions Matrix poster (from Lesson 10)



Review and incorporate peer feedback into community plans. Tell students to return to their original groups and process the feedback that the stayers received from other groups as well as the ideas that the strayers got from the other presentations. Display slide I to suggest a structure for reviewing and incorporating feedback.

Say, *We use peer feedback to improve our work, making it clearer, more accurate, and better supported by evidence.*

- Communicate the feedback each pair received on their ideas as stayers.
- Decide whether you agree or disagree with the feedback, and talk with your group about why you agree or disagree.
- Communicate the new ideas each pair got from their peers when they strayed.
- Decide whether you agree or disagree with these new ideas, and talk with your group about why you agree or disagree.
- Revise your work to address the feedback and new ideas.

ADDITIONAL GUIDANCE

Some students might not feel comfortable highlighting the changes they made to their design solutions based on peer feedback, because they think they might get a lower score. Make sure they understand that what matters in this step of the design process is their ability to respond to the feedback and to justify the changes they make.

Reflect on the challenge process. Present slide J and say, *Take a moment to stop and jot in your science notebook to reflect on the Design Challenge process by answering the question: How did the presentations change your thinking about how complex it is to make these kinds of decisions for a community?* After a few minutes, ask for volunteers to share their responses. Accept all responses.



Assign home learning. Present slide K and say, *It can be hard to give and receive feedback. Before next class, spend some time reflecting on how you did today giving and receiving feedback using the Peer Feedback Self-Assessment handout.* Distribute *Peer Feedback Self-Assessment* to each student.

At the end of the period, make sure students have turned in their posters and pamphlets, or given you access to their slides and videos.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Look for students to write clear questions regarding the alignment of their peers' proposed design solutions, the reliability of their designed system, and the criteria the class has identified for weighting tradeoffs. (SEP: 1.4; DCI: ETS1.B.1; CCC: 7.4)
- Ask clarifying questions about the values and interested parties represented in the design solution. (SEP: 1.4; DCI: ETS1.B.1)
- Ask clarifying questions that can help others think about additional changes in the system that can be tried in the grid calculator in order to improve the reliability of the system and/or its alignment with the criteria for success established by the class. (SEP: 1.4; DCI: ETS1.B.1; CCC: 7.4)

What to do: Make sure the Consensus Decisions Matrix poster is visible in the classroom. Encourage students to point to the criteria included on the poster when asking other groups about the alignment between their design solution and these criteria.

Encourage students to also think like different interested parties and see whether the proposal would represent the values and interests of these parties.

Building toward: 11.B Ask questions to identify and refine criteria for success for our design solutions, including reliability (stability) and social, cultural, and environmental impacts. (SEP: 1.4, DCI: ETS1.B.1; CCC: 7.4)

End of day 2

9 · NAVIGATE: MAKING CONNECTIONS

5 min

MATERIALS: None

Review our progress. Ask students to turn and talk about the prompts on slide L:

- *How did our investigations over the course of this unit help us understand what structures can function to make our energy systems stable, even when conditions change?*
- *How did our investigations over the course of this unit help us build a foundation for understanding energy conservation and energy transfer that we can take forward into the rest of the year?*

Elicit 2-3 ideas quickly. Accept all responses.

10 · RETURN TO THE DRIVING QUESTIONS BOARD

20 min

MATERIALS: science notebook, tape, *Reviewing Our DQB*, Driving Questions Board

Work in pairs to evaluate what DQB questions the class has answered. Display slide M. Provide each pair of students with one copy of the *Reviewing Our DQB* handout, which you created to contain all the student questions from the DQB. Have students work with their partner to mark questions they think the class has answered:

- *We did not answer this question or any parts of it yet: ○ or ?*
- *Our class answered some parts of this question, or I think I could answer some parts of this question: ✓*
- *Our class answered this question, or using the ideas we have developed, I could now answer this question: ✓✓*

If you have time, have students pick three questions they think the class has answered. Tell them to use the space on the handout to write down the answer to those questions.

Discuss the questions the class can now answer. Present slide N. Have the class discuss the answers to those questions. If you have space, you could make a “Takeaways” board as a record of the answers that the class has come up with.

Pose the unit question, and celebrate how far we have come. To close out the discussion, pose the DQB question, or pose the unit question: *How can we design more reliable systems to meet our communities’ energy needs?*

Say, We should be proud of all we have accomplished in this unit. We have answered so many of our questions, and developed a deep understanding of energy transfer and conservation that we can carry forward into the rest of our physics course, as we investigate a wide variety of other natural and designed phenomena. Now you will have the opportunity to demonstrate everything you have learned while exploring another power solution as part of a transfer task.

11 · ADMINISTER THE FINAL TRANSFER TASK

20 min

MATERIALS: *Sand and Mirrors Transfer Task*, calculator, science notebook.



Set the context for the assessment. Say, *In this unit, we learned about a lot of sources of power that are fairly common. But to build better power systems for our communities, some engineers are thinking outside the box.*

Administer the assessment. Present slide O. Distribute the *Sand and Mirrors Transfer Task* to each student. Give them 20 minutes to complete the task.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: See *Sand and Mirrors Assessment Key*.

What to do: Use the key to assess students. Use it also for suggestions on how to provide productive feedback for students who are working with foundational ideas but not yet linking them, students who are linking ideas but not yet organizing them, and students who are organizing their ideas and need an additional challenge.

This assessment is not building toward a lesson-level performance expectation. It is designed to assess a performance expectation from the NGSS, below.

Transfer Task PE: 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 motions of particles (objects) and energy associated with the relative positions of particles (objects). (SEP: 2.3, 4.6, 5.5; DCI: PS3.A.1, PS3.A.2, PS3.A.4, PS3.B.1, PS3.B.4, PS3.D.1, ETS1.B.1; CCC: 5.2, 5.3)

Additional Lesson 11 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

This is the CCMS-related idea that is used to support sensemaking in this lesson:

Number and Quantity

- CCSS.MATH.CONTENT.HS.N-Q.1 **Quantities:** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

While students complete the *Sand and Mirrors Transfer Task*, encourage them to include the units in every step of the process. Some might be tempted to skip the steps for rearranging the values, which can lead to mathematical errors. Encourage students to write every step they follow to solve their calculations. Allow them to see their notes for similar calculations they have done during the unit.



Unit P.1 Teacher Reference Materials



ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial models Driving Question Board	Pre-Assessment The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model developed on day 2 of Lesson 1 is a good opportunity to pre-assess student understanding of which parts of the system are important for explaining what happened in Texas. The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as how and why questions and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway.
Lesson 6	<i>Wire Simulation Investigation, Simulation Investigation Key</i> <i>Motors Transfer Task, Motors Transfer Task Key</i> Optional: <i>Transformer Transfer Task</i>	Formative In lesson 5, students get a chance to make a claim about the relationship between two variables in a simulation of electricity moving through a wire, and then plan and conduct an investigation, and analyze the data to use as evidence to either support or refute their claim. Summative In this assessment, students get a chance to use what they have figured out about generators to model and explain energy transfer in a motor. An additional parallel task is included (<i>Transformer Transfer Task</i>) as an option for students who might benefit from another opportunity to take a similar assessment after receiving feedback. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments.
Lesson 8	L8 Electronic Exit Ticket, <i>L8 Electronic Exit Ticket Key</i>	Summative This electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations from Lessons 7 and 8, which function together as a problematize/putting the pieces together routine for the first lesson set of the unit. This assessment is designed to be easy to gather information about where your students are still struggling to put the pieces together.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 9	<i>Modeling Reliability, Modeling Reliability Key</i> <i>Peer Modeling Rubric, Peer Feedback Self-Assessment</i> <i>Testing Battery Storage Solutions, Testing Battery Storage Solutions Key</i>	Formative Students make a complex energy transfer model to show how adding a battery could improve the reliability of the electric grid. They incorporate many of the conventions and ideas we have developed across the unit. Self-Assessment Students are asked to complete a self-assessment where they reflect on how well they gave and received feedback on the modeling task. Formative Students get the opportunity to practice computations coherently (in the context of figuring out the phenomenon), before being expected to use those same computations in the Lesson 10 electronic Exit Ticket and the final Transfer Task.
Lesson 10	L10 Electronic Exit Ticket, <i>L10 Electronic Exit Ticket Key</i>	Formative This electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations from Lessons 9 and 10. This assessment is designed to be easy to gather information about where your students are still struggling to apply certain practices in the context of engineering.
Lesson 11	<i>Design Challenge, Design Challenge Key</i> <i>Peer Interactions Support, Peer Feedback Self-Assessment</i> <i>Sand and Mirrors Transfer Task, Sand and Mirrors Assessment Key</i>	Summative In this lesson students put all the pieces together to design a plan for their community. The task requires them to poll stakeholders, consider how values impact tradeoff decision making in engineering, and choose criteria and constraints. They will need to apply what they have learned about electrical energy sources and systems to complete the assignment, including energy loss and efficiency. This culminating task was designed to give students and educators the chance to engage in “transformative social and emotional learning.” Transformative SEL describes a process “whereby young people and adults build strong, respectful, and lasting, relationships that facilitate co-learning to critically examine root causes of inequity, and to develop collaborative solutions that lead to personal, community, and societal well-being.” Rather than provide students with a fictional scenario, the task is designed to support students in taking agency, and to give students the tools to speak up in their local and global community for a better energy future, one that aligns with their values. Self-Assessment Students are asked to complete a self-assessment where they reflect on how well they gave and received feedback on the modeling task. Summative At the end of this final lesson, students will have the opportunity to demonstrate their competence with a transfer task.
Occurs in several lessons	Lesson Level Performance Expectation Assessment Guidance	Formative Assessment Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.

When	Assessment and Scoring Guidance	Purpose of Assessment
Occurs in several lessons	<i>Progress Tracker</i> <i>Engineering Design Tracker, Engineering Design Tracker Examples</i> <i>Decisions Matrix</i>	Formative and Self-Assessment The Progress Trackers are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Trackers are meant to be a thinking tool for kids, we strongly suggest it is not collected for a summative “grade” other than for completion. In this unit, students add to their <i>Progress Tracker</i> in Lessons 1, 2, 5, 6, and 7. Examples of models and ideas students may include in this tracker are embedded in these lessons. This unit also includes a second progress tracker specifically for engineering ideas, called the <i>Engineering Design Tracker</i>. Students add to their <i>Engineering Design Tracker</i> in Lessons 3, 6, 8, 9. This resource is accompanied by a key in Lesson 9 with examples of what these entries might look like. This unit also includes a <i>Decisions Matrix</i>, which students will use alongside the Engineering Design Tracker in Lesson Set 2 to make decisions about what designs they would like to advocate for in their community as the electric grid ages. This resources is introduced in Lesson 4, and revisited in Lessons 10 and 11.
Occurs in several lessons	Student Self Assessment Discussion Rubric	Self-Assessment This resource is available in the OpenSciEd Teacher Handbook. The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small group discussions can be more productive. In addition to this flexible resource, self-assessment has been written directly in the unit in Lessons 9 and 11.
Occurs in several lessons	Peer Feedback Facilitation: A Guide	Peer Feedback This resource is available in the OpenSciEd Teacher Handbook. There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. We suggest that peer review happen at least two times per unit. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process. Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work, rather, peer feedback will be more valuable to students if they have time to revise after receiving peer feedback. It should be a formative, not summative type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback. In addition to this flexible resource, peer feedback has been written directly in the unit in Lessons 3, 9, and 11.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to [Science and Engineering Practice\(s\)](#), alignment to [Cross-Cutting Concept\(s\)](#), and alignment to the [Disciplinary Core Ideas](#).

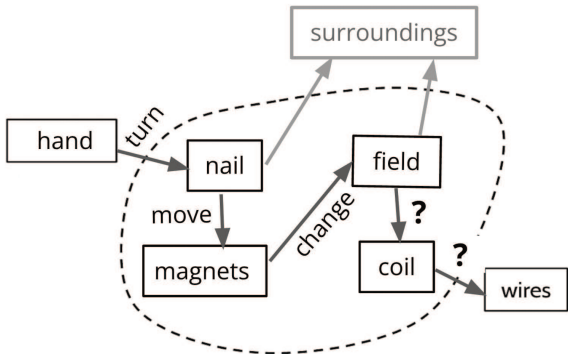
The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	1.A Develop a model of energy transfer through systems to explain how energy manifests as electricity in our communities, including how changes to an otherwise stable system could cause blackouts. (SEP: 2.3; CCC: 7.1; DCI: PS3.A.2, PS3.B.2, PS3.B.4) 1.B Ask questions to clarify and define the problem of how our community can generate energy by designing systems to address both local and global challenges. (SEP: 1.4; 1.8; CCC: 4.1; DCI: ETS1.A.2)	1.A When to check for understanding: On day 2 when students do their initial model gallery walk. In addition, you can collect initial models at the end of day 2 to assess students' ideas more closely after class. What to look for/listen for in the moment: Modeling more than one system; for example, the power plant, the wires, and the houses. (SEP: 2.3) - Indication of energy transfer between systems; for example, arrows connect systems, or the systems are drawn in a line, and/or the student indicates energy transfer in their written responses to questions 3 and/or 4 on <i>Initial Models</i>. (SEP: 2.3; DCI: PS3.A.2, PS3.B.4) - Second model indicates a clear change to the system, and the repercussions of that change in terms of energy transfer (a blackout). (CCC: 7.1; DCI: PS3.B.2) 1.B When to check for understanding: During the development of the Driving Question Board (DQB). What to look for/listen for in the moment: Questions about specific systems; for example, the power plant, the wires, and/or the building. (SEP: 1.4) Questions that go beyond mechanistic explanations (e.g., "How does a generator work?") to explore design challenges and tradeoffs (e.g., "How can we prevent something like the Texas blackouts from happening in our community?" or "How can we make energy production more green?"). (SEP: 1.4; CCC: 4.1) Questions that define specific local or global challenges that students noticed in the anchor and/or bring from their own experience (e.g., pollution, job creation, disparities in electricity access). (SEP: 1.8; DCI: ETS1.A.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	2.A Collect data from a designed system (a power strip) and a network of interconnected subsystems (multiple powerstrips) on the interactions needed for and failure points in the transfer of electrical energy. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1) 2.B Develop, revise, and use a model to identify analogous structures that affect the electrical energy transfers across and between different (sub)systems at different scales (a powerstrip versus a building). (SEP: 2.3; DCI: PS3.B.2; CCC: 4.1, 6.1)	2.A When to check for understanding: When groups dissect power strips and use them to power devices with one battery on day 1. - Investigation A (Dissection) - Investigation B (Powered Circuit) What to look for/listen across 1-2: - Identifying at least two parts and/or interactions they observe inside (CCC: 4.1) the powerstrip. - Observations and tests that may include - Connecting alligator clips to different metal parts to determine which connections are needed for energy transfer from the battery to each light bulb and recording the results. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1) - Testing the effect of the switch and noticing it turns on or off all devices together. When the wire connected to the switch isn't used for any devices, the switch does nothing. (SEP: 3.6; CCC: 4.1) - Connecting additional devices in certain configurations (e.g., parallel versus series) either does or does not appear to affect the amount of energy transferred (brightness) to each light bulb. (SEP: 3.6; DCI: PS3.A.3; CCC: 4.1) 2.B When to check for understanding: - When you collect students' models of the power strip system at the end of day 1 after Investigation B (Powered Circuit). - When you discuss the structures in a building on day 2, using ideas students gathered from <i>Electricity Related Parts</i>. What to look for/listen for across 2.B.1 and 2.B.2: - Models of the power strip system are analogous to a circuit diagram, showing which parts in the system need to be connected in order for the system to work as designed for energy to transfer from the source to multiple devices. (SEP: 2.3, DCI: PS3.B.2; CCC 6.1) - Identification of analogous structures and functions between two designed systems at different scales (a building versus a power strip). (SEP: 2.3, CCC 4.1, 6.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 3	3.A Develop and use a model based on evidence from our investigation in Lesson 2 to illustrate the energy flow between components of the electric grid system and energy loss from the system as a possible cause of the crisis in Texas. (SEP: 2.3; DCI: PS3.B.2, PS3.D.1; CCC: 4.3) 3.B Evaluate the impact of empirical data about energy supply and demand from Texas in February 2020 and 2021 to identify patterns, and evaluate how scientific knowledge and constraints impact possible solutions. (SEP: 4.5, 6.5; DCI: PS3.B.4; CCC 1.5, Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World)	3.A When to check for understanding: On day 1, when students develop energy transfer models for Scenarios A-E on <i>Energy Transfer Scenarios</i>. What to look for/listen for in the moment: - Modeling energy transfer across more than one system (e.g., the power plant, substation, and buildings) and using question marks to indicate areas of uncertainty. (SEP: 2.3) - Using numbers or symbols to quantify energy coming in and out of various parts of the system (e.g., the buildings, power plant, and/or substation). (CCC: 4.3) - Indicating that the energy coming into the substation from the power plant is equal to the total energy leaving the substation to buildings and the surroundings. (DCI: PS3.B.2, PS3.D.1) - Models for Scenarios A and B include an arrow to indicate a connection between parts of the electric grid and the surroundings, to account for the energy loss in the system. (CCC: 4.3) 3.B.1 When to check for understanding: On day 1 when students fill in their <i>Engineering Design Trackers</i>. What to look for/listen for in the moment: Look for students to recognize and write about constraints (e.g., cost, space, etc.) on undergrounding power lines that will make it more difficult for communities to implement that design solution. (SEP: 6.5; Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World) 3.B.2 When to check for understanding: On day 2, when students use the Identify and Interpret (I²) Strategy to analyze the electricity demand forecast, electricity demand, and electricity production data from Texas in 2020 and 2021. What to look for/listen for in the moment: - Concise descriptions of patterns (similarities, trends, or changes) presented in the graphs, such as: - the rapid increase in electricity demand from February 14 to February 17 of 2021 - the almost perfect match of supply and predicted demand in 2020 - the mismatch between energy demand and supply during the energy crisis in 2021 - Reasonable inferences about patterns that emerge from the data, such as: - People used more power when it got cold because they needed to heat their homes. - Power companies make enough supply to match demand when the system is functioning properly. - When supply does not match demand, people will lose power. (SEP: 4.5; DCI: PS3.B.4; CCC 1.5)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	4.A Analyze multiple types of data to identify characteristics of energy sources derived from Earth's systems that increase the reliability of the energy grid (a criterion for success), given that for the system to remain stable, it must be designed for energy supply to meet energy demand. (SEP: 4.6; DCI: ESS3.A.2; DCI: PS3.B.4; CCC: 7.4)	4.A.1 When to check for understanding: When students first see the <i>Energy Source Cards</i> on day 1 (slide D). What to look for/listen for: As you move around the room, ask students the first question on the slide, and listen for them to make the connection that almost all of these sources come from Earth's systems, except solar. (DCI: ESS3.A.2) 4.A.2 When to check for understanding: When we discuss how we change reliability into a criterion after the ranking gallery walk on day 1 (slide H). What to look for/listen for: Students can explain that in order for the system to remain stable, it must be designed for supply to meet demand. (DCI: PS3.B.4; CCC: 7.4) 4.A.3 When to check for understanding: On day 2, when we build understanding as a class (slide O). What to look for/listen for: Students identify patterns in the data and can explain what they mean, relating their ideas back to reliability. (SEP: 4.6)
Lesson 5	5.A Develop a model based on evidence to illustrate the energy and matter changes in a generator, including energy transfer through contact between moving parts and energy transfer at a distance through fields. (SEP: 2.3, DCI: PS3.A.2, PS3.A.3; CCC: 5.2) 5.B Design and build a generator system to transfer motion energy to light that meets agreed-upon criteria, manipulating variables and collecting data to identify failure points and improve performance. (SEP: 3.6, DCI: PS3.A.2; CCC: 4.1)	5.A.1 When to check for understanding: On day 1, when students work with a partner to create an energy transfer diagram for the natural gas power plant in <i>Power Plant Diagrams</i>. What to look for/listen for in the moment: - Students should use our box and arrow conventions, and label the arrows with at least one action word to describe energy transfer. (SEP: 2.3) - Energy transfer arrow labels should describe interactions, even partially. These energy transfers will generally manifest as matter changes or motion changes (e.g., fire heats emissions, steam pushes turbine, turbine pushes generator). It is not important that students recognize interactions as forces in this unit. (DCI: PS3.A.2; CCC: 5.2) - Students will likely not yet have a clear idea of how energy transfer manifests in the wires. This uncertainty will motivate the investigations in Lesson 6. Rather than pushing them to figure this out now, encourage them to highlight this limitation of their model by putting a question mark on that arrow. (DCI: PS3.A.2) 5.A.2 When to check for understanding: On day 3, when students complete their class consensus model about their homemade generators. What to look for/listen for in the moment: As a class, students should model something like this:

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		 - Students should again use our box and arrow conventions, and label the arrows with at least one action word to describe energy transfer. (SEP: 2.3) - The class model should include energy transfer to a field with the arrow labeled as “change” (i.e., magnets change the field). (DCI: PS3.A.3; CCC: 5.2) - Students will likely not yet have a clear idea of how energy transfer manifests in the wires. This uncertainty will motivate the investigations in Lesson 6. Rather than pushing them to figure this out now, encourage them to highlight this limitation of their model by putting a question mark on that arrow. (DCI: PS3.A.2) 5.A.3 When to check for understanding: On day 3, when students individually complete their exit tickets. What to look for/listen for in the moment: - Students should say that the motion of magnets causes field changes, resulting in the transfer of energy. (DCI: PS3.A.3; CCC: 5.2) - Students should identify parts on their model where the magnets move and where the field changes, generating electrical energy. (SEP: 2.3, CCC: 5.2, PS3.A.3) - Students should have questions about what is happening in the wire when energy transfers through it. We haven’t yet introduced electrons, but students who have taken chemistry or physics may mention electrons or electric current as a place to go next. 5.B When to check for understanding: On day 2, as students plan, build, test, and improve their homemade generators. What to look for/listen for in the moment: - Students identify design criteria relevant to the generator’s performance, transferring motion energy to light (i.e., lighting multiple bulbs, lighting a bulb for an extended time). (SEP: 3.6, DCI: PS3.A.2) - Students evaluate their own design against the agreed-upon criteria as they build and test their generator design. (SEP: 3.6, CCC: 4.1) - Students use the Design Challenges on the handout to improve their designs in real life. (SEP: 3.6) - Students describe a relationship between a specific design variable (e.g., magnet spinning speed, magnet position, number of wire coils) and the energy output (e.g., “If we spin the nail faster, the light is brighter”). (SEP: 3.6)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 6	6.A Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about motions of particles or energy stored in fields. (SEP: 8.2; DCI: PS3.A.3; CCC: 2.2) 6.B Use a simulation to model electron flow inside a wire in order to identify patterns, answer questions, and determine relationships between independent and dependent variables involving electrical energy transfer that can be interpreted to reengineer and improve the electric grid. (SEP: 1.3; DCI: PS3.A.4; CCC: 1.3) Transfer Task 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. (SEP: 2.3, 6.5; DCI: PS3.A.2, PS3.A.3, PS3.D.1; CCC: 5.2)	6.A When to check for understanding: On day 1, when students model passages from <i>Changing Fields</i>, and later model the inside of a wire; and on day 2, when students share conclusions from the simulation and connect these conclusions to in-class experiments. What to look for/listen for in the moment: - Fields store and transfer energy. In energy transfer diagrams, students should label the energy transfer arrow into a field with the word “change” or the like. Energy transfer arrows from a field to a particle, such as an electron, should be labeled “push” or the like. (DCI: PS3.A.3) - Information about fields obtained from a reading is consistent with evidence we have seen in class. We can incorporate both to model energy transfer in wires. (SEP: 8.2; DCI: PS3.A.3) - We can use particle-scale mechanisms for interactions between particles and fields to identify cause-effect relationships for larger systems like a wire, and to explain evidence of energy transfer we have seen in class, such as compasses moving and wires heating up. (DCI: PS3.A.3; CCC: 2.2) 6.B When to check for understanding: On day 2, as students work to fill out <i>Wire Simulation Investigation</i>; and on day 3, when students use their conclusions from day 2 to complete their <i>Engineering Design Tracker</i>. What to look for/listen for in the moment: - Use <i>Simulation Investigation Key</i> as guidance. - Increasing the wire length and/or decreasing the wire width results in less energy transfer and more energy loss. (SEP: 1.3; DCI: PS3.A.4) - Lower wire temperatures result in slightly more energy transfer and slightly less energy loss, but the effect is small. (SEP: 1.3; DCI: PS3.A.4) - We can use these conclusions to reengineer our electric grid. We will waste less energy if we use thicker wires and minimize wire length by keeping energy sources as close to their destination (buildings) as possible. (CCC: 1.3) - These choices have trade-offs and constraints--energy sources such as coal plants can be unhealthy for residents, and thicker wire costs more money. (CCC: 1.3) Motor Transfer Task: On day 3 (a half day), administer the <i>Motors Transfer Task</i>. This assessment is not building toward a lesson-level performance expectation. It is designed to assess progress toward a performance expectation from the NGSS (HS-PS3-3). See the accompanying <i>Motors Transfer Task Key</i> for details. <i>Transformer Transfer Task</i> is included as an option for offering parallel tasks, or a retake, and can be assessed using the same key. (SEP: 2.3, 6.5; DCI: PS3.A.2, PS3.A.3, PS3.D.1; CCC: 5.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 7	7.A Develop a model showing how insufficient supply entering the system could lead to reduced energy transfer into certain communities in Texas when the temperatures dropped, resulting in buildings losing power. (SEP: 2.3; DCI: PS3.B.4; CCC: 5.2, 5.3) 7.B Develop and test a correlational hypothesis to investigate tradeoffs inherent in making decisions about energy, and then consider limitations on this analysis to motivate seeking information about patterns at a smaller grain size. (SEP: 1.6, 4.2, 4.3; DCI: ETS1.B.1; CCC: 2.1, 3.3)	7.A When to check for understanding: When students are modeling in groups on day 1, and during the consensus modeling immediately afterward. What to look for/listen for: Note that this task is designed to highlight gaps in our understanding. Do not expect students to accurately model what happens when there is not sufficient energy in the system; they should recognize that when supply does not meet demand, the system will not function, and they should use the appropriate conventions to make this clear. • Students use the energy transfer conventions we developed in Lesson 3 to represent systems and energy transfer between systems. • The subsystems students choose to include may vary, but look for systems to be labeled clearly. At the least, they should include a power plant (or energy source), a transport system (or substation), and at least two communities (or homes/buildings in a community). (SEP: 2.3) • Students indicate that insufficient supply results in power loss, either by labeling the appropriate buildings as blacked out, using an X to indicate no energy transfer, erasing (or not drawing) lines indicating energy transfer, and so forth. (DCI: PS3.B.4) • Students use numbers, dots, or some other quantitative representation to show that the amount of energy entering the system is equal to the amount of energy available to homes, minus any energy lost to the surroundings. • Students may choose to reduce supply, increase demand, or both, as long as they show that supply did not meet demand. • If students choose to show energy loss to the surroundings, this loss is reflected in the amount of energy available to homes. (CCC: 5.2, 5.3) 7.B.1 When to check for understanding: Collect students' <i>Texas County Data Analysis</i> handouts at the end of day 2. What to look for/listen for: • Use <i>Texas County Data Analysis Key</i> to look for students to explain why their variable might be related to power loss by making connections to human engineering decision-making or to natural causes (Question 2). (DCI: ETS1.B.1) • Use the key to look at students' hypotheses (Questions 3-4), data analysis (Questions 4-8), and current thinking about limitations (Question 9). (SEP: 1.6, 4.2, 4.3) • Use the key to look at the way students are talking about correlations (Questions 6-8). (CCC: 2.1) 7.B.2 When to check for understanding: Use the conversation about limitations at the end of day 2 as an opportunity to pre-assess how students are understanding the distinction between data sets at various grain sizes. What to look for/listen for: • Data grouped by counties might not capture the details of how variables are distributed across communities. (CCC: 3.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 8	8.A Integrate quantitative information, visual information, and audio (or text) to define some of the challenges and tradeoffs associated with a drop in energy supply driven by cold weather, and consider additional tradeoffs associated with making energy decisions. (SEP: 8.2; CCC/NOS: 5.2, 5.3; Science Addresses Questions About the Natural and Material World; DCI: ETS1.A.2, ETS1.B.1)	8.A.1 When to check for understanding: When students discuss key takeaways from the podcast as a class (slide C). What to look for/listen for in the moment: - Listen for students to reference ideas they heard in the podcast in conjunction with the graphs they saw projected over the podcast (or in the accompanying handout). (DCI: ETS1.A.2, ETS1.B.1) - Listen for students to identify at least one tradeoff related to decisions made by the power company. The most obvious tradeoff is related to cutting power to protect essential buildings and power plants at the expense of people in certain communities. But listen for more nuanced tradeoffs as well, such as that between weatherizing power plants versus cost, or between reliability in a storm versus using wind/solar power to avoid burning fossil fuels. (SEP: 8.2) - Listen for students to recognize that if energy going into the grid is spread too thin, there will not be sufficient energy in the system to keep electrons in the wires moving fast enough. This could cause the whole grid to shut down, causing weeks of widespread outages. (CCC: 5.2, 5.3) Electronic Exit Ticket: The Electronic Exit Ticket at the end of this lesson is designed to address the lesson-level performance expectations from Lessons 7 and 8, which function together as a problematizing/putting-the-pieces-together routine for the unit's first lesson set. This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together.
Lesson 9	9.A Develop an energy transfer model to predict the stability in the distribution of electric energy when batteries are present and absent from the system. (SEP: 2.3; CCC: 7.4; DCI: PS3.B.1, PS3.B.4) 9.B Apply ratios, rates, percentages, and unit conversions to calculate the costs and land area of use of a design solution to evaluate its feasibility for preventing an energy crisis like the one in Texas in 2021. (SEP: 5.5; DCI: ETS1.B.1; PS3.D.1; CCC: 3.1)	9.A When to check for understanding: On day 1, after students complete <i>Modeling Reliability</i>. What to look for/listen for in the moment: Use <i>Modeling Reliability Key</i> to assess the handout. (SEP: 2.3; DCI: PS3.B.1, PS3.B.4; CCC: 7.4) 9.B When to check for understanding: On day 2, after students complete <i>Testing Battery Storage Solutions</i>. What to look for/listen for in the moment: Use <i>Testing Battery Storage Solutions Key</i> to score the handout. Look for students to: - Show units in their calculations, and the conversions they make for costs, efficiency, and land area of use. (SEP: 5.5) - Support their claims about feasibility using their calculations. (SEP: 5.5; DCI: ETS1.B.1, PS3.D.1; CCC: 3.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 10	10.A Define the problem, and then interview various interested parties in our community to identify criteria that can help make decisions to improve the electricity infrastructure, including how it is designed for reliability (stability) and its social, cultural, and environmental impacts. (SEP: 1.4, 1.8; DCI: ETS1.B.1; CCC: 7.4) 10.B Analyze data generated by interviews with community members to specify criteria for success related to energy solutions, such as monetary cost, safety, and reliability, and weigh cost/benefit tradeoffs related to social, cultural, and environmental impacts. (SEP: 4.6; DCI: ETS1.B.1; CCC: Influence of Science, Engineering, and Technology on Society and the Natural World, Science Is a Human Endeavor)	10.A When to check for understanding: At the end of day 1, as students complete the <i>Interview Protocol</i>. What to look for/listen for in the moment: • A clear definition of the problem we are trying to solve (designing a more reliable electric grid system that satisfies various criteria for success and the values of various interested parties) that can help interviewees understand the value of their input. (SEP: 1.4, 1.8; DCI: ETS1.B.1; CCC: 7.4) • Questions that look to identify and clarify which criteria are most important to interested parties. (SEP: 1.4; DCI: ETS1.B.1) 10.B When to check for understanding: On day 3, as students complete the Electronic Exit Ticket. What to look for/listen for in the moment: Use the <i>L10 Electronic Exit Ticket Key</i> to assess student work in multiple dimensions. This task is designed to target lesson-level performance expectations from lessons 9 and 10.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	11.A Define a problem related to the challenge of improving our electrical grid, and then design, evaluate, and refine a solution, taking into account social, cultural, and environmental impacts (both intentional and unintentional), based on results from a computational model, scientific knowledge we have figured out over the unit, weighted criteria, and tradeoff considerations. (SEP: 1.8, 2.6, 6.5, DCI: ETS1.A.2, ETS1.B.2, ESS3.A.2; CCC: 1.3) 11.B Ask questions to identify and refine criteria for success for our design solutions, including reliability (stability) and social, cultural, and environmental impacts. (SEP: 1.4, DCI: ETS1.B.1; CCC: 7.4) Transfer Task PE: 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 motions of particles (objects) and energy associated with the relative positions of particles (objects). (SEP: 2.3, 4.6, 5.5; DCI: PS3.A.1, PS3.A.2, PS3.A.4, PS3.B.1, PS3.B.4, PS3.D.1, ETS1.B.1; CCC: 5.2, 5.3)	11.A.1 When to check for understanding: On day 1, after students complete Question 2 of the <i>Design Challenge</i> using the Energy Grid Calculator. What to look for/listen for in the moment: Use the <i>Design Challenge Key</i> for assessment support. (SEP: 1.8, DCI: ESS3.A.2, ETS1.B.1) 11.A.2 When to check for understanding: At the end of day 1, when students complete Part 2 of the <i>Design Challenge</i>. What to look for/listen for in the moment: Use the <i>Design Challenge Key</i> for assessment support. (SEP: 1.8, 2.6, 6.5; DCI: ETS1.A.2, ETS1.B.2, ETS1.B.1; CCC: 1.3) 11.B When to check for understanding: At the end of day 2, when students are engaged in the stayer-strayer protocol. What to look for/listen for in the moment: - Look for students to write clear questions regarding the alignment of their peers' proposed design solutions, the reliability of their designed system, and the criteria the class has identified for weighting tradeoffs. (SEP: 1.4; DCI: ETS1.B.1; CCC: 7.4) - Ask clarifying questions about the values and interested parties represented in the design solution. (SEP: 1.4; DCI: ETS1.B.1) - Ask clarifying questions that can help others think about additional changes in the system that can be tried in the grid calculator to improve the reliability of the system and/or its alignment with the criteria for success established by the class. (SEP: 1.4, DCI: ETS1.B.1; CCC: 7.4) Transfer Task: When to check for understanding: On day 3, administer the <i>Sand and Mirrors Transfer Task</i>. This assessment is not building toward a lesson-level performance expectation. It is designed to assess a performance expectation from the NGSS (HS-PS3-2). See the <i>Sand and Mirrors Assessment Key</i> for guidance. (SEP: 2.3, 4.6, 5.5; DCI: PS3.A.1, PS3.A.2, PS3.A.4, PS3.B.1, PS3.B.4, PS3.D.1, ETS1.B.1; CCC: 5.2, 5.3)



Lesson-Specific Teacher Materials



Example Community Agreements

Physics Community Agreements	
Respectful Our classroom is a safe space to share.	• We provide one another with support and encouragement. • We share our time to talk. We do this by giving others time to think and share. • We critique the <i>ideas</i> we are working with but not the <i>people</i> we are working with.
Equitable Everyone's participation and ideas are valuable.	• We monitor our own time spent talking. • We encourage others' voices who we have not heard from yet. • We recognize and value that people think, share, and represent their ideas in different ways.
Committed to our community We learn together.	• We come prepared to work toward a common goal. • We share our own thinking to help us all learn. • We listen carefully and ask questions to help us understand everyone's ideas. • We speak clearly and loud enough so everyone can hear.
Moving our science thinking forward We work together to figure things out.	• We use and build on others' ideas. • We use evidence to support our ideas, ask for evidence from others, and suggest ways to get additional evidence. • We are open to changing our minds. • We challenge ourselves to think in new ways.

Lesson 2 Teacher Reference

Preparing Cardboard Buildings

As an alternative to simple paper tents, you can prepare one of these cardboard building structures for every small group in your largest class. Students can decorate the building to personalize the “electric city” they build as a class. **Safety Note:** Use caution when using sharp (scissors, etc.), which can cut or puncture skin.

Open the ends and glued edges of a used soda can or sparkling water can container.



After separating the last glued edge, flip the material inside out.



Reassemble the box, securing the edges for all the faces except one, using tape.

Note: You could also use the box as is, without flipping it inside out, if the images on the outside are not too distracting.



Mark the location of a couple of windows and a door to cut out.



Use scissors or a box cutter to cut out the windows and the door.



Slide the power strip into the box to test the fit. Cut away a small hole in the last flap for the cord to stick out of. Don't tape this last flap closed.

Make sure the plugs have been cut off the power strips you are using (this is not shown in the images here).

Remove the power strip and repeat the previous steps for the next box you need to make.



Lesson 3 Teacher Reference

Discussion Mapping Tool

Instructions

1. Print one copy of the second page of this tool for each class section.
2. Add students' names to the circle in the order that students are sitting. You may want to do this ahead of time, and then ask students to sit according to the map.
3. Write the question that students are trying to answer at the top of the page.
4. Select a student recorder who will map the discussion as it happens. Decide ahead of time whether you will have multiple students take turns mapping, and when you will move the map to a new student recorder.
5. If this is the first time you are using a discussion map, explain to students that each time someone speaks, the recorder will draw a line from the previous speaker to the new speaker's name. You may want to mark where the conversation begins and ends, but the goal is to map the overall conversation patterns rather than to be able to retrace the entire conversation.
6. Once the discussion begins, allow students to take the lead in moving the discussion forward. Sit in the circle as a participant rather than standing in front of the class as a facilitator. This will allow students to practice building on each other's ideas directly.
7. Be mindful of group dynamics, especially when displaying the map and discussing patterns of contributions. Avoid focusing on the contributions of single students, and instead redirect the class to notice class-level patterns.

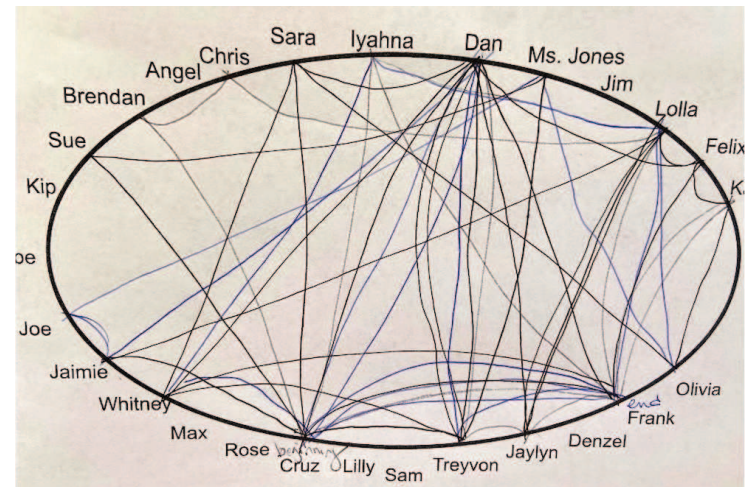
An example of a completed discussion map is pictured below:

Discussion Mapping Codes

The key at the bottom of the discussion map contains codes that can be used to label the types of student contributions. The first few times you create a discussion map with your students, you should focus only on recording the flow of the conversation. This allows students to get comfortable with the process. Once students have experience recording and interpreting those initial patterns, you can add discussion mapping codes to future discussion maps. There is an extra column where you can add your own discussion codes as needed, based on individual class needs and agreements. You may also choose to only use some of the discussion codes, based on the type of discussion your students are having. In this case, be sure to cross out the codes you are not using so the student recorders know not to include them.

Key Ideas

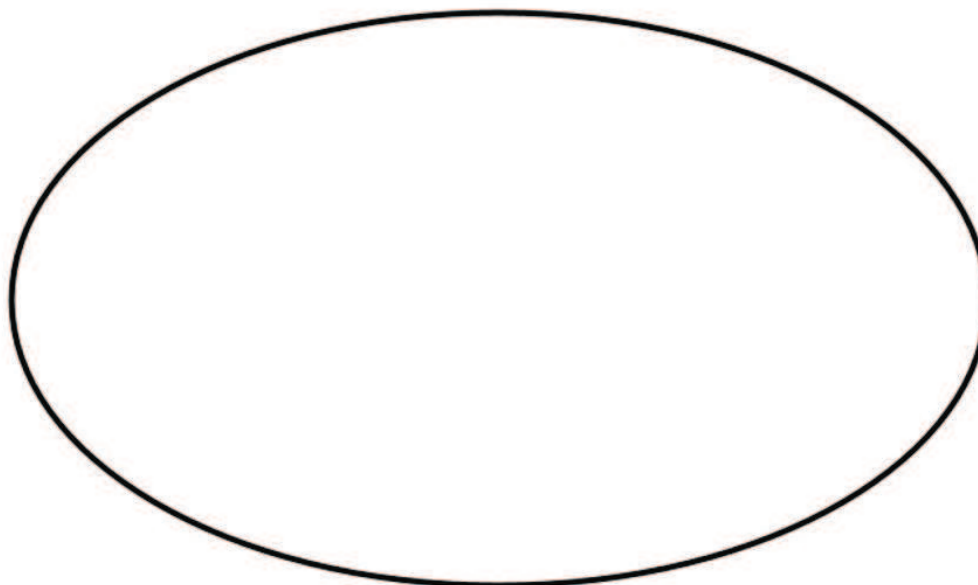
There is space to list up to three key ideas that emerge from the discussion on the tool itself, so the class can keep track of the ideas raised in the discussion. If you choose to use codes to annotate student contributions, you can also use the codes "1", "2", and "3" to map when those ideas are talked about.



Question we are trying to answer:

Directions:
Write your students names around the circle, according to where they are sitting in the room.

Tip:
Find a landmark for you and add it to your image!



Key Idea 1:

Key Idea 2:

Key Idea 3:

Discussion Mapping Codes					
C- claim given	CL- clarified idea	? - asked question	T- tied ideas together	I- interrupted	1- Key Idea 1
E- gave evidence	A- affirmed/agreed	NI- new idea added	RP- related phenomena		2- Key Idea 2
OT- off topic	D- disagreed	R- repeated idea	•- idea ended		3- Key Idea 3

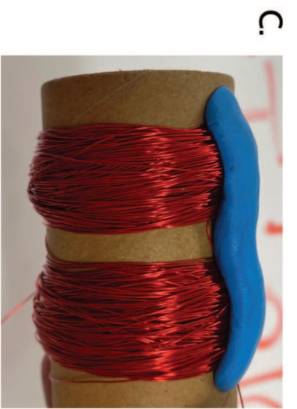
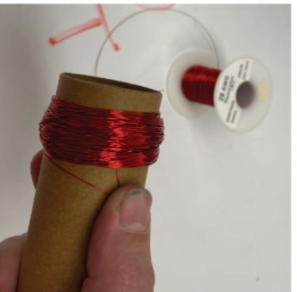
Preparing Generator Materials

Materials (for 5 groups to make their own generators):

- safety glasses with side shields or safety goggles and work gloves.
- 8 1.57" paper tubes--similar to toilet paper tubes, but thicker cardboard
- 5 heavy steel nails, 5-6" long and 1/4" diameter (size 60D nails ideal)
- 10 cylindrical neodymium magnets, $\frac{3}{8}$ " diameter, $\frac{3}{8}$ " height
- 1,000-2,200 ft of 28AWG magnet wire
- sticky tack
- sandpaper or a sharp blade
- nail polish (or permanent marker)
- 10 alligator clips and 5-10 ultra-bright LEDs
- (optional) power drill with 2 speeds

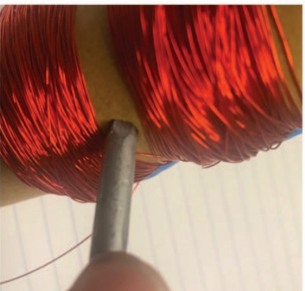
Preparing generator tubes: (For guidance, see <https://youtu.be/1arsLDIZ6XM>.)

1. Leaving 4 inches (10 cm) of loose wire at 1 end, wrap 1 paper tube in 200-400 tight wraps of magnet wire, about 1 cm in from 1 end (A). **Do not** wrap in the center of the tube.
2. Continue wrapping in a new position closer to the center of the tube, leaving 1 cm between the 2 groups of wraps. The second wraps will be the same as the first, for a **total of 400-800 tight wraps**. Attempt to get each coil as close as possible to the position of the spinning magnets, as coils further from the magnets will work much less effectively. For 400 coils, it's ideal to wrap such that the **furthest coils are less than 2 cm from the center point** (where the nail is inserted into the tube). **The two outermost coils should be no more than 4-5 cm apart.**
3. Finish by twisting the wire around itself 3-4 times in an overhand knot fashion (B), then pull tight. Leave 4 inches of loose wire at the other end and cut the wire. Use a thin strip of sticky tack to secure the wraps against the tube. If any parts of the wrap seem loose, secure them with sticky tack (C).



4. Use a nail to poke a hole in the cardboard tube in the space between the 2 groups of wraps (D). Push it through the other end of the tube, making sure the nail goes directly through the middle of the tube, leaving $\frac{1}{2}$ " of space on both sides for magnets to spin (E). Slide and spin the nail in and out until it rotates freely inside the 2 holes you've made, then remove the nail.
5. Use sandpaper or a sharp blade to scrape $\frac{3}{4}$ " (2 cm) of red insulation off the edges of the magnet wire on each loose end (E). Scrape around the wire so the orange copper wire is visible on all sides.

D.



E.



F.



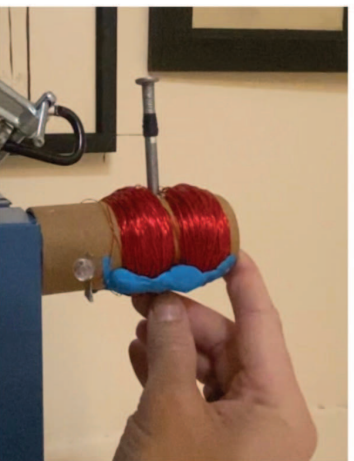
6. Use nail polish (or permanent marker, though this will quickly rub off) to label the same side of each magnet with a dot of color. An undamaged compass should point to the magnet's N pole. Alternatively, **2 poles are identical if they repel each other. Do not** use attraction to the nail to identify poles--both sides of the magnet will attract the nail.

7. For Challenge 4, students need tubes with different numbers of wraps. Prepare 3 tubes with different numbers of wraps (e.g., 100 wraps, 200 wraps). If your main tubes have 700+ wraps, provide 1 tube with 400 wraps. If your main tubes have 400 wraps, provide 1 tube with 700 wraps if possible. **Label the tube's total number of wraps in permanent marker on the tube.**

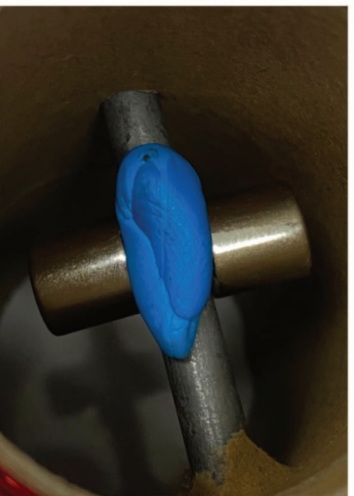
Supporting student work:

1. Refer to *Generator Engineering Task* to get familiar with students' 4 design challenges. If students spend most of their time on Challenges 1 and 2, this is fine. All students need time and space to **create a working generator** and come to conclusions about how **changes in magnets** inside the coil generate electricity in the wires.
2. Students need to spin the nail hard to light the LED. Slow turns won't work. They may want to wrap string around the nail and pull, or hang something from the string (G), or even use an electric drill to spin the nail. Have some useful materials available so students can try their ideas.

G.



H.



3. In Challenge 3, note that "out of place" magnets will generate about 20% less electric energy, though they may still light up an LED. Suggest to students that they might secure the magnet with 2 small wads of sticky tack. If they're struggling, show them they can place 1 wad of sticky tack between the magnets (H) and push it down against the nail. Students can push a similar wad against the other side, then keep pushing the wads into the nail on both sides until the magnets are correctly positioned.
4. Before class ends, students may prepare materials for the next class. Ask them to remove sticky tack from the nail. They can then pull the nail out of the tube, and the magnets will drop. You can then separate magnets from each other by pushing them sideways until you can peel them apart.

Notes about wire wrapping:

Wrapping the wire can be tedious and the wire itself can be expensive, **but more wire wraps will indeed create a better generator**. Our recommendation is to use the most wraps that you can, given the availability of magnet wire.

- The ratio of wraps to feet of wire is about 2.2 wraps per foot. 400 wraps is about 180 ft of wire; 550 wraps is 250 ft, 730 wraps is 330 ft.
- **OKAY**: 1 spool of 500 ft of 28AWG magnet wire can construct 3 tubes with 380 wraps each. Students may have trouble seeing the LED light up unless they find a way to spin the nail very quickly. An electric drill will likely not spin fast enough to light 1 LED.
- **GOOD**: 1 spool of 500 ft of 28AWG magnet wire can construct 2 tubes with 550 wraps each. These generators will work well, and students will see 1 LED blink on briefly as they flick the nail. However, more than 2 LEDs likely won't light when students try to light their entire power strip "city," and an electric drill may not light even 2 LEDs.
- **EXTREME (in a good way)**: 1 spool of 2,000 ft of 28AWG magnet wire can construct 6 tubes with 730 wraps each. These generators will be fairly powerful, and students will easily see the LED light continuously by tugging a string wrapped around the nail. The generator will light 6+ LEDs easily when students try to light their power strip "city." However, the coil of wire is quite large, so it may fall off the tube if more sticky tack isn't used to secure it.

If you need to "splice" 2 wires together, first secure existing wraps temporarily with sticky tack so the wraps don't unwind. Sand/scrape the enamel insulation off about 2 cm of the end of both wires, then twist them together at least 5 times. Keep twisting or cut off the excess, then tuck the twisted connection into the existing wraps. Remove the temporary sticky tack and keep winding tightly.

If a tube becomes damaged, it is possible to rewrap the wire onto a new tube. Remove the sticky tack from outside the old tube, as well as the nail and magnets, and use a ring stand or something similar as an "axle" for the old tube. "Untie" the original overhand knot at the end of the old wrapping, then wrap the wire around the new tube, taking care to keep tension on the wire at all times. **Do not get interrupted or distracted during this rewrapping, or you can end up with an unpleasant mess.**

Safety Reminders:

1. Wear sanitized safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of the activity.
2. Use caution when using sharp (tools, wires, nails, etc.), which can cut or puncture skin.
3. Use caution when operating a power drill. Operator needs a 3+ foot clearance from observers.
4. Plug power drill into GFI protected circuit and keep away from water sources to prevent shock.
5. Powerful magnets can snap together and pinch fingers. Keep the magnets far apart when not in use.
6. Use gloves to prevent pinched fingers when working with magnets.
7. Keep magnets at least 20 cm away from sensitive electronic and data storage devices.
8. Keep flammables (e.g., nail polish) away from active flames or sparks to prevent fire.
9. Make sure all materials and equipment are returned to the appropriate location upon completing activities.
10. Make sure all materials and equipment are returned to the appropriate location upon completing activities.
11. Wash your hands with soap and water immediately after completing this activity.

Ammeter Construction Directions

Follow these steps to build an ammeter. This video https://www.youtube.com/watch?v=F_vvuk_GjIU&list=PLSLDxpPb5NQmKp9RwUjciB82h4QO6x4G_&index=9 also shows these same steps.

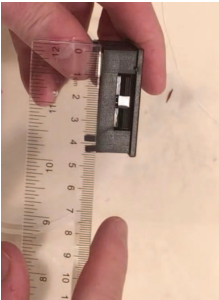
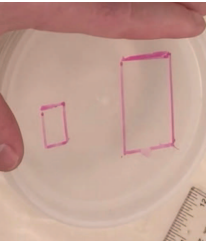
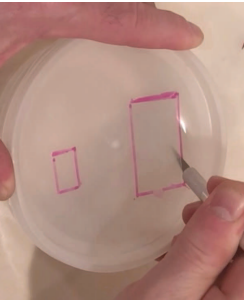
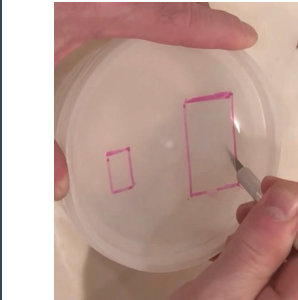
Each ammeter you build will require these materials:

- LED voltmeter ammeter, red and blue digital multimeter display voltage current tester (DC 0-100V 10A)
- 9V battery connector
- 2-pin rocker boat switch
- 9V battery
- 8 oz deli container (bowl and lid)

These materials will be reused or divided across all the ammeters you build:

- ruler
- utility knife
- scissors
- marker
- roll of electrical tape (1 ft)

Stage 1: Fitting holes in the lid

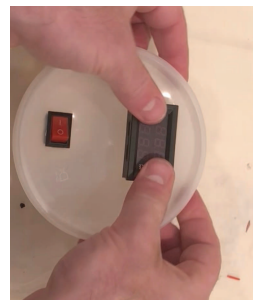
Instruction Steps	Associated Images	
Measure the dimensions of the base of the LED voltmeter ammeter.		
Draw a rectangle with those same dimensions on the top half of the deli container lid.		
Measure the dimensions of the base of the switch as well.		
Draw a rectangle with those same dimensions on the bottom half of the lid.		
Secure the lid to the deli container bowl.		
Cut out the two rectangles you drew on the lid, using a box cutter or hobby knife.		
Remove the lid and remove the pieces you cut out.		

Secure the lid to the bowl.

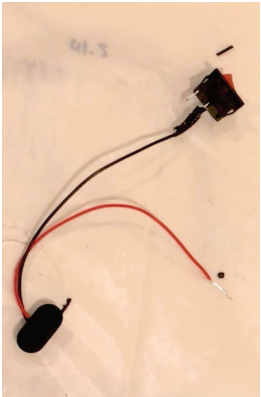
Push the LED voltmeter ammeter into the large rectangular hole in the lid.

Push the switch into the small rectangular hole in the lid.

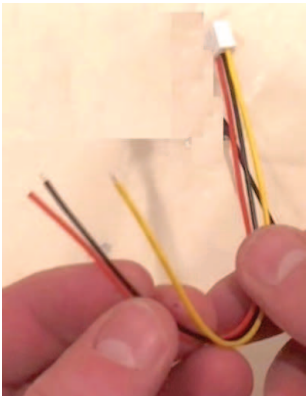
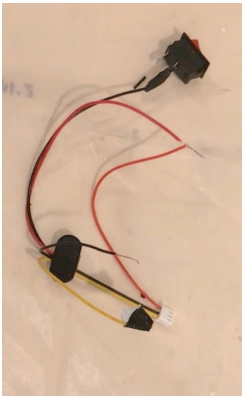
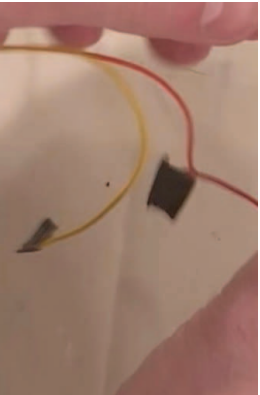
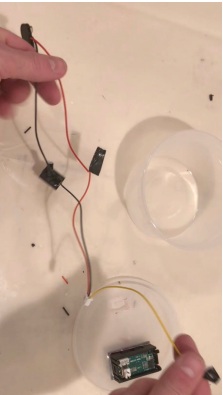
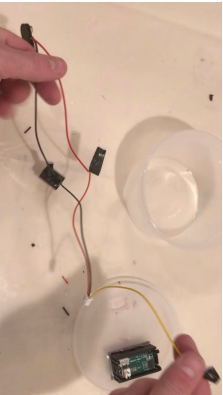
Once you've confirmed these fits, remove the lid and remove the switch from the small hole for now.



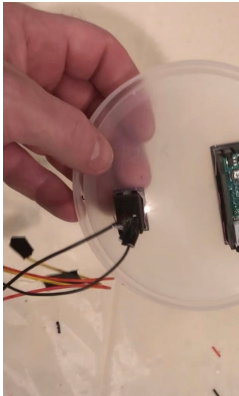
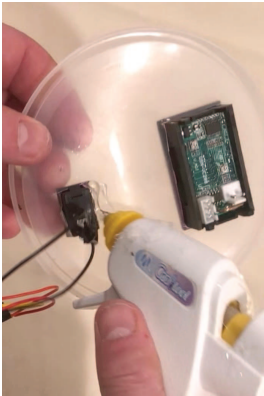
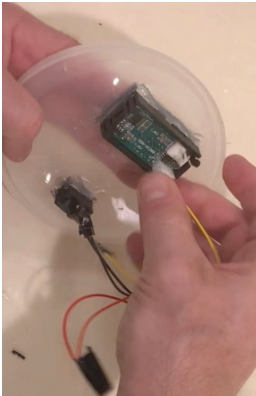
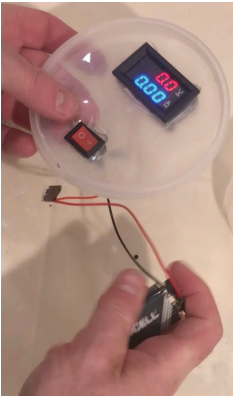
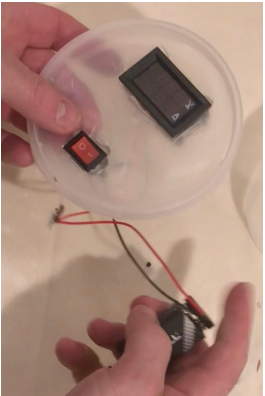
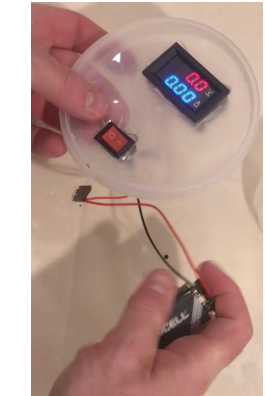
Stage 2: Attaching the battery connector to the switch

Instruction Steps	Associated Images	
Strip ½"-1" of insulation off the end of each wire on the 9V battery connector. You can do this by using the end of a pair of scissors opened up a bit and held together lightly. Drag the end of each wire through the scissor blades. This should pull the insulation off.		
Thread the stripped end of the black wire of the battery connector through the hole in one of the metal prongs on the back of the switch.		
Wrap a small piece of electrical tape around this twisted end and the metal prong on the switch, so no metal is visible. The image to the far right shows how the battery connector is attached to the switch at this stage of the build.		

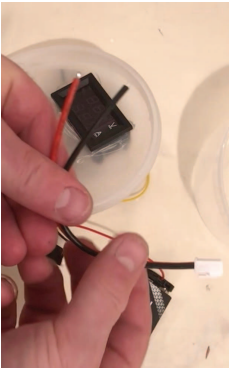
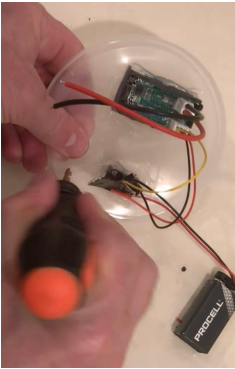
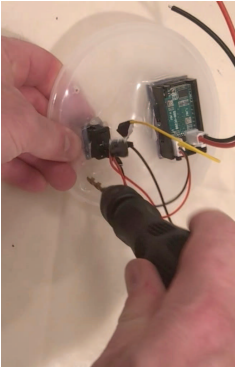
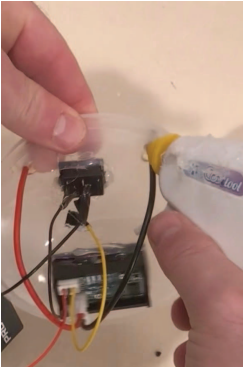
Stage 3: Hooking up the first adapter to the switch and battery connector

Instruction Steps	Associated Images	
Find the three wire adapters included in the package of the ammeter panel. Strip ½"-1" of insulation off the end of the red wire and the black wire. Do not do this for the yellow wire.	 	
Twist the exposed end of the red wire you just stripped to the exposed end of the red wire from the battery connector. Wrap a small piece of electrical tape around the twisted end of these wires. Wrap a small piece of electrical tape around this end of the yellow wire. This wire is for measuring voltage and is not used in this unit.	 	
Thread the exposed end of the black wire you just stripped through the hole in the other metal prong on the back of the switch. Twist the end of the wire back on the rest of the wire, like you would a twist tie. Wrap a small piece of electrical tape around this twisted end and the metal prong on the switch, so no metal is visible. The image to the far right shows the assembly at this stage of the build.	 	

Stage 4: Hooking up the power source to the ammeter panel

Instruction Steps		Associated Images	
Thread the battery connector through the small hole in the lid.			
Pull all the related wires through as well, so only the switches are left on the outside of the lid.			
Push the switch flush into the hole, so all the wires attached to it and the battery connector are on the back side of the lid.			
Use the hot glue gun to put a bead of glue along where the edges of the switch meet the lid on the back side of the lid.			
Do the same for the LED voltmeter ammeter.			
Push the white coupling clip for the three-wire adapter to the bottom white port on the back of the ammeter panel, aligned so the clip can snap into the port.			
Attach a 9V battery to the battery connector.			
Turn on the switch to test that the ammeter display turns on.			
Turn off the switch for now.			

Stage 5: Positioning the circuit leads

Instruction Steps		Associated Images	
Find the two wire adapters included in the package of the ammeter panel.			
Push the white coupling clip for the wires into the top port on the back of the ammeter panel, aligned so the clip can snap into the port.			
Use the hand drill from Lessons 2 and 3 to make two holes in the lid.			
Put one hole on each side of the lid below where the switch is located, about 1" away from the switch.			
Thread the red wire through the left hole (when seen from the front of the lid).			
Thread the black wire through the right hole (when seen from the front of the lid).			
Use the hot glue gun to put a bead of glue along where each wire meets the lid.			
Do this on both the front and back of the lid.			
Turn on the switch to test that the ammeter panel still works.			
Guide all the wires and the battery into the bowl.			
Secure the lid to the bowl. You may want to test the connections by giving the container a slight shake. If the connections between all the twisted wires remain, the panel will remain powered.			

If the panel's power goes off when you shake it, disassemble the container and pinch various connections that are taped where you twisted the wire together. When you find and pinch the loose one, the power will go back on. Take the tape off that location, tighten that connection, tape it back up, and test it again.

Lesson 6 Teacher Reference

Real-Life Investigations Prep

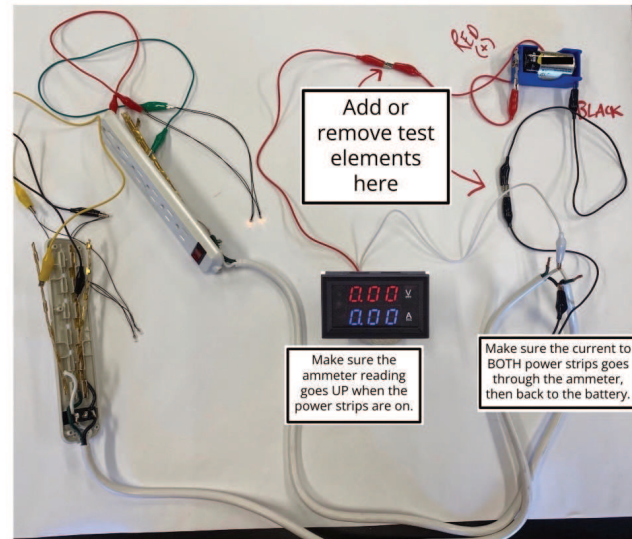
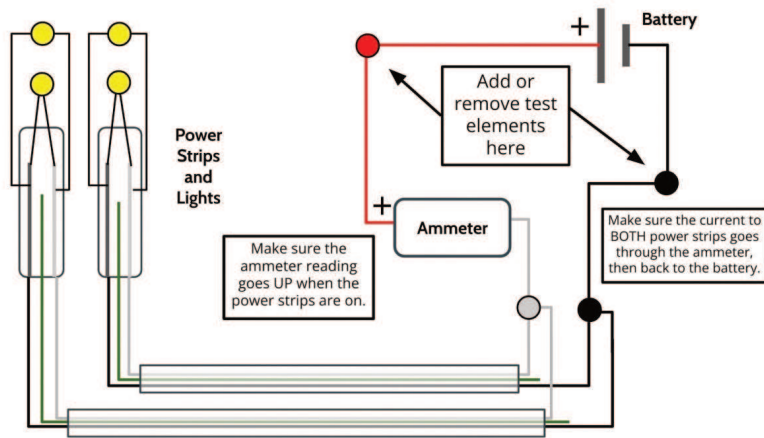
Due to the limited time available, it's worth setting up the materials in advance so the maximum time possible is spent actually carrying out investigations rather than troubleshooting wire connections.

The setup shown here is similar to that in the simulation, because it allows students to turn two different circuits on and off to see the effect on the total current passing through the battery.

Plan to begin your experiments by pointing out what happens to the ammeter reading when all lights are turned off versus when one or two power strips are turned on. Students should have noticed in the simulation that the total current equals the current passing through each individual circuit added together; this is an opportunity to point that out.

Notice the following:

- The ammeter is connected such that the reading goes **up** into the positive range when the lights are turned on.
- The ammeter is measuring the total current from the battery to **both** power strips, not the current to only one power strip.
- The “Add or Remove Test Elements Here” portion of the circuit makes it easier to introduce new elements to see the effect they have on the current, such as wires of different lengths, or a wire coil that can be heated or cooled to two different temperatures.

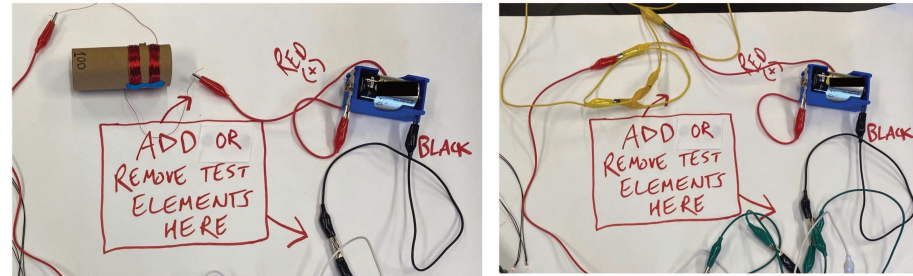


Follow students' lead for other experiments they suggest.

You can use **two** coils of wire from the generator experiment with different numbers of wire wraps (100 and 400, for example), because students will notice that the generator wire is narrower than the alligator clips, and changing two variables at the same time results in an unclear conclusion.

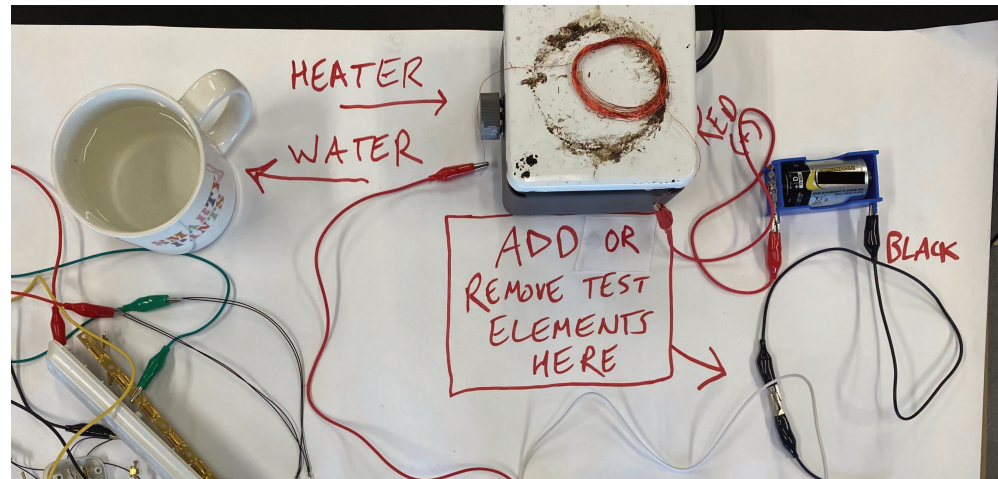
Alternatively, the wire length can be changed significantly by adding more alligator clips, though the corresponding change in current will be rather small.

If you have materials available to show the effect of wire width, you can do this experiment as well. Students may suggest that two wires side-by-side could have the same effect as a wider wire, but if they do not suggest this, do not force this idea upon them. Instead, focus on wire length and temperature as a way to verify the simulation results more generally.



To show the effect of temperature, use a coil of wire on a hot plate, or another source of heat or cold available in your classroom, such as a cup of ice. If you use a hot plate, the enamel-insulated magnet wire is not ideal, because the enamel will melt. If uninsulated wire is available, this is ideal. Even though the wire is coiled, the current will not travel through the length of the coil without insulation, but this is not a bad thing for this demonstration.

It is unlikely that you will notice any significant change in current as a result of changing temperature. Though students may have concluded that “As *wire temperature increases, electric current decreases*” in the simulation, this effect is tiny in real life. Guide students to the understanding that tiny changes are usually less important than obvious ones. In this case, “As *wire temperature increases, electric current doesn’t change much*” is a valid conclusion, and is more relevant to our work than focusing on how we might refrigerate the wires in our electric grid!



Simulation Investigation Key

Go to <https://www.openscienced.org/general/acdc/> - Click "Setup" then "Go / Pause".

1a. Slide "*wire-length-to-source*" up and down. What changes do you notice in the sim?

Repeat for "*wire-diameter*", "*wire-temperature*", and "*wire-material*". What do you notice? Which changes in the system are modeled visually, and which changes require you to use your imagination?

- Length and diameter don't change, but the number changes.
- Changing temperature makes the larger particles move faster.
- Changing material makes the color change.
- I have to use my imagination for material, length, and width, but I can see temperature changes visually.

1b. Which particles are *atoms* and which particles are *electrons*? How does the motion of atoms change when the wire temperature increases? How do the electrons move?

- atoms = larger particles, don't move as far, move faster when temperature increases
- electrons = smaller, move farther, bounce off each other, aren't affected by atoms

2. Notice the yellow box labeled "% **energy loss to surroundings**". Click on a light switch to turn on a light, and notice the value of this yellow box. What factors in the sim seem to affect this number?

- Clicking at least one switch makes a number appear for % energy loss.
- Length, width, and material all affect this number a lot. Temperature affects it a little.

3. Turn on "**attach-ammeters**" in the green box. This value measures **electric current** in mA--that is, how much charge flows through the wire each second. What factors seem to change these values? How do the 3 current values near switches A, B, and C compare to the current value near the battery?

- Length, width, and material all affect these values.
- The three current values near the switches add up to the value near the battery.

PLAN YOUR RESEARCH QUESTION:

4. What is 1 relevant ***dependent variable*** (DV) that you can measure with a number in the simulation to help answer our questions about matter changes and energy transfer in a wire?

- % energy loss to surroundings **or** electric current

Note: Measuring the "brightness" of the light bulbs or the "speed" of the electrons is also valid, but it can't be measured with a number. If students are interested in either of these variables, encourage them to find another variable that seems related. Say, *Are there any numbers that seem related to electron speed?* Or, say, *Are there any numbers that seem to go up or down when the bulb brightness goes up or down?*

5. What is one relevant ***independent variable*** (IV) that you can choose to change in the sim to help answer our questions about matter changes and energy transfer in a wire?

- wire length **or** wire width **or** wire temperature **or** number of lights on
- Note: Changing the material is also valid, but it cannot be expressed as "increases" in Q8 below. If a student has selected "material", inform them that they may need to answer questions about another independent variable as well.

6. A **research question** can often be stated as, "*What is the effect of (independent variable) on (dependent variable)?*" Write your research question using 2 variables below.

What is the effect of wire length on % energy loss to surroundings?

independent variable (from Q5)

dependent variable (from Q4)

CONDUCT YOUR INVESTIGATION

7. Investigate a relationship between the independent and dependent variables you chose:

- A. Run the simulation and notice the value of your dependent variable.
- B. Pause the simulation and **increase** the independent variable value.
- C. Run the simulation again and note any change in the dependent variable.
- D. Repeat steps B and C until you are sure you've identified a pattern.

E. **Controlled variables are factors that we keep constant** so we can see how the independent variable affects the dependent variable. List at least 2 or 3 variables that you **didn't change** while investigating your relationship.

All other answers from Q5 that a student **didn't** choose should be held constant. For example, if a student chose length as their IV, controlled variables include: width, temperature, material, and number of lights on.

8. Write your results as a statement below:

When wire length increases, $\rightarrow$ IV

(DV $\rightarrow$) % energy loss to surroundings increases / decreases / doesn't change much*
(circle one)

When temperature increases, $\rightarrow$ IV

(DV $\rightarrow$) % energy loss to surroundings increases / decreases / doesn't change much*
(circle one)

** What does "change much" mean here? Scientists have to make this call themselves.*

Note: Students may be focused on the small change in current and % energy loss when they change the value of temperature. That's OK, but point out that the meaning of "change much" is a decision that scientists have to make themselves. If you have a chance to do the temperature-current experiment in real life, students will ultimately agree that the current doesn't change much.

9. How could we run a similar experiment in our classroom with real equipment to determine whether the simulation matches the real results? Write down the materials you would need and some instructions below, then get your teacher's attention to show them what you came up with.

Materials: wire of different lengths, ammeter, light bulb to measure energy, battery

Instructions: Connect a light bulb to a battery with an ammeter next to the battery. Increase the length of the wires connecting the battery to the bulb, and see whether the brightness of the bulb changes or the ammeter number goes up or down.

Materials: heater, ice water, wire, ammeter, light bulb to measure energy, battery

Instructions: Connect a light bulb to a battery with an ammeter next to the battery. Get a piece of wire that can be heated up (it can't have rubber insulation, because that might melt), and heat it up with a heater while it's connected to the battery and bulb. See whether the number on the ammeter changes as the wire heats up. Carefully pick up the hot wire and dunk it in the ice water to cool it down, and see whether the brightness of the bulb changes or the ammeter number goes up or down.

ANALYZE YOUR RESULTS

10. Discuss at your table any connections you see between your results and (a) the energy crisis in Texas in 2021 or (b) how to improve our electric grid. What conclusions can you make?

- a. Results about temperature can be connected to the energy crisis. We may have thought that decreasing temperature could make it harder for current to flow, but we see that decreasing temperature actually slightly increases current, decreasing energy loss to the surroundings.
- b. Results about wire length, width, and material can be connected to how to improve our grid. Building the grid out of shorter wire or thicker wire, or choosing copper wire over nickel wire,

can all increase current and decrease energy loss. This also means that we might build power plants closer to users, so the wire doesn't have to be as long.

11. Repeat Questions 6-7 for more research questions: *What is the effect of ___ on ___?*

For each experiment, write or say a statement like Question 7 to describe your results.

- As wire length increases, energy loss increases and current decreases.
- As wire width increases, energy loss decreases and current increases.
- As temperature increases, energy loss and current don't change much (energy loss increases slightly and current decreases slightly).
- Some materials cause much less energy loss and more current than other wires. Copper and silver cause less energy loss; nickel, stainless steel, and Nichrome cause more energy loss.

Lesson 6: Answer Key 2

Motors Transfer Task Key

Performance expectation being assessed: 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.** (SEP: 2.3, 6.5; DCI: PS3.A.2, PS3.A.3, PS3.D.1; CCC: 5.2)

This assessment does not address the following DCI, which is secondary to this performance expectation **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 it can be determined whether a given design meets them. This DCI is addressed in the Lesson Set 2and is assessed in the final Transfer Task.

In addition to the SEP, CCC, and DCI associated with this PE, this assessment also addresses one additional SEP element and one additional DCI element, described below:

3D Elements Addressed in the Assessment				Question #		
				1	2	3
SEPs	2.3 Developing and Using Models. Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	X	X	X		
	6.5 Constructing Explanations and Designing a Solution. 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.					X
DCIs	PS3.A.2: Definitions of Energy. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HSPS3.A)	X	X	X		
	PS3.D.1: Definitions of Energy. Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3), (HS-PS3-4)		X	X		X
	PS3.A.3 Definitions of Energy. “Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. (secondary to HS-PS2-5)		X			X
CCCs	5.2 Energy and Matter: Flows, Cycles, and Conservation. Changes of energy and matter in a system can be described in terms of flows into, out of, and within that system. The total amount of energy and matter in closed systems is conserved.	X	X	X		
	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.					X

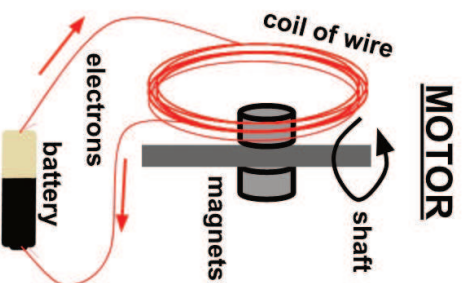
Motors Transfer Task

When we transfer kinetic energy into a system that uses magnets and a coil of wire to generate electricity by moving something in the system, we call the system a **generator**. In a **generator**, magnets transfer energy from motion into changing magnetic fields, which then transfer energy to changing electric fields. These electric fields cause electrons to move and transfer electrical energy along the wire. Therefore, one way to think about a generator is as a device that transforms *kinetic energy* (motion) into *electrical energy*.

However, when we transfer *electrical energy* into a system that uses magnets and a coil of wire to turn a shaft, we don't call the system a generator. Instead, we call it a **motor**.

In a **motor**, moving electrons from a source causes a change in the field around a coil of wire. This field will push and pull the magnets. This will cause the shaft to move.

Imagine that a student draws this energy transfer diagram of a **motor**:



Q1. Provide constructive feedback to this student using the following prompts:

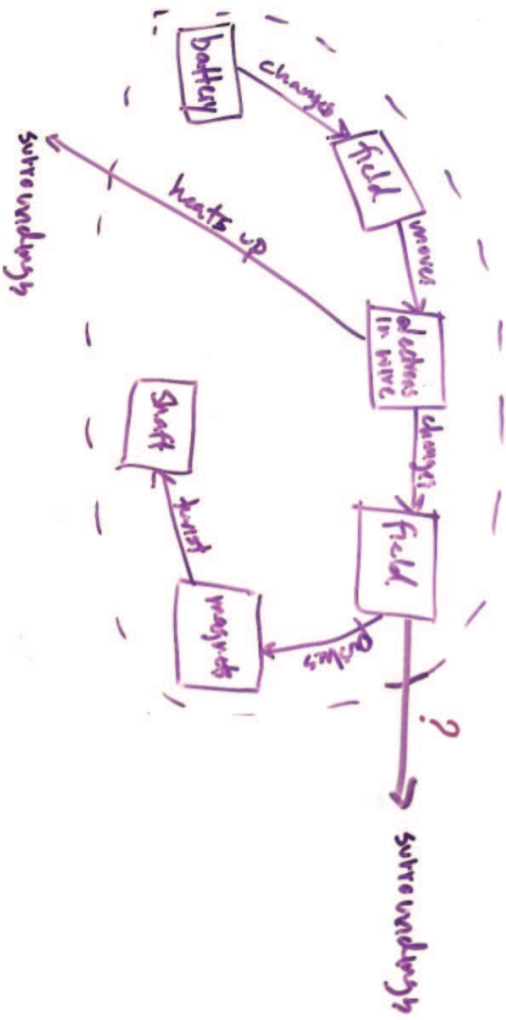
- What parts would you suggest the student add?
- What interactions would you suggest the student add or label?
- What other changes would you suggest the student make to this diagram?

I think the student should add fields between the battery and the wire, and between the wire and the magnets.

I think the student should label the arrows as the battery changes the field, which moves electrons in the coil of wire, which changes another field, which pushes the magnet, which twists the shaft.

Put in energy amounts, add energy loss to the surroundings, and bound the system.

Q2. Redraw the energy transfer diagram. In your diagram, make sure to include energy transfer out of the system to the surroundings. Use verbs on arrows to show and describe energy transfer, and include all relevant objects and interactions (even those that are invisible or too small to see). Do the best you can to show how much energy is transferring, and how much is lost out of the system.



Q3. A student builds a motor, but the shaft doesn't move when they connect the coil to a battery. The student feels the coil of wire and notices that it is warm. They remove the magnets and find that they attract and repel strongly.

- a. Look back at the energy transfer diagram you created. From where to where is energy definitely still transferring in the broken motor? Describe the energy transfer mechanism, and support your claim with evidence that the student collected from the broken motor.
- b. Identify a mechanism from the energy transfer diagram you drew that might prevent enough energy from transferring to the shaft. Describe the energy transfer mechanism, and support your claim with evidence that the student collected from the broken motor.
- c. What suggestion(s) do you have for troubleshooting the student's motor to transfer more energy to the motion of the shaft?

Rubric for Question 3 (continued on next page)

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	Look for: Students suggest a way to refine the motor, but make no connections to evidence from the device or to energy transfer. (SEP: 6.5)	Look for: Students suggest an evidence-based way to refine the motor and relate it to energy transfer, but do not point to mechanisms for how energy transfers through the system. (SEP: 6.5; CCC: 5)	Look for: Students use evidence that the student collected from the broken motor and from their energy transfer models to describe how energy transfers between systems from their energy and/or out of the system. (SEP: 6.5, 2.3; CCC: 5.2; PS3.A.2, PS3.B.4) AND Students connect these ideas to suggest an evidence-based way to refine the motor so sufficient energy will transfer to the shaft. (SEP: 6.5, 2.3; CCC: 5.2) (Some students may describe energy leaving the system through the hot wires, and why this is inefficient.)

Example	Part a The wire. Part b The battery. Part c Try a stronger battery.	Part a The wire is still warm, so energy is probably transferring to it. Part b The magnets might be the wrong way, or there needs to be more wire. Part c Try adding more wire, and try flipping the magnets around.	Part a The wire is warm, so the battery must be transferring energy to it. The magnets work, so they can transfer energy to changing the field if they move. Part b Just because the magnets are strong doesn't mean energy is transferring between the wire and the magnets. Maybe the magnets are the wrong way, which would affect the shape of the magnetic fields so energy can't transfer. Also, maybe it is not enough energy. Maybe there are not enough coils of wire, or not enough electricity. Part c They could try holding the magnet close to the coil to see whether they attract or repel when the battery is connected. Or, if there is just too much energy transferred to the surroundings, maybe they could use wider wire or increase the battery strength to get faster electrons and a bigger change in field.
Feedback	Linking: Ask students to brainstorm evidence that we've seen of energy transfer, and jot down notes. If possible, encourage students to use language consistent with the energy transfer diagrams to record ideas (example: "electrons heat up wire").	Organizing: Encourage students to think about the role of the system. Say, <i>What does it mean for energy to stay inside the system here? Where have we seen energy leave the system, and why?</i>	Extending: Challenge students by asking them to consider what they could do to prevent energy loss from the wire. They might suggest changing the thickness of the wire or adding insulation. Students may notice that the motor as described could not (even theoretically) turn continuously--the most it could "move" would be $\frac{1}{2}$ turn, if the magnets and the coil begin in opposition. "Simple motor" designs have developed a few clever ways to solve this problem, and students should be asked to describe how this aspect of the motor design they've proposed would work.

	Foundational Understanding	Linked Understanding	Organized Understanding
How to modify instruction	As a follow-up, ask students to get out their copy of the field reading, and try modeling a few bolded passages that could connect to the motor (example: “battery changes field, field pushes electrons”). After students have a concrete grasp of incorporating this language into energy transfer, direct them back to Q3. Say, “What evidence of energy transfer do you see in the description of Q3? Judging from this, what components do you know are definitely transferring energy?”	The most concrete energy connection is the energy loss to the surroundings from the wire. Guide students to the understanding that moving electrons can change the field, and then say, “In the simulation of the wire, what do you remember changing to make the electrons move faster? What would that mean for the motor?”	If you have spare magnet wire, it’s possible to use it to build a simple motor. Encourage students to inspect the design proposed here, and research how to “build a simple motor” online to propose a design that might function similarly.

Lesson 7: Answer Key

Texas County Data Analysis Key

3D Elements Addressed in the Assessment	2	3	4	5	6	7	8	9
Asking Questions and Defining Problems: 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.	X	X	X					
Analyzing and Interpreting Data: Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.			X	X	X	X	X	
Analyzing and Interpreting Data: Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.							X	
Cause and Effect: Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.	X					X		
ETS1.B.1 Developing Possible Solutions: When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	X							

Part 1: Choose a Variable of Interest

☐ Population ☐ Hospitals ☐ Acute Care Beds ☐ Hospitals per 100,000 ☐ Acute care beds per 100,000 ☐ % Black ☐ % White ☐ % Asian ☐ % American Indian or Alaska Native ☐ % Native Hawaiian or Pacific Islander	☐ %Multiracial ☐ % Hispanic or Latino ☐ Density (# People per square mile) ☐ Poverty Quintile ☐ Income per person ☐ Income per household ☐ Land Area ☐ Water Area ☐ Total Area	☐ Percent Urban ☐ Percent Rural ☐ % High School Graduate or Higher ☐ % Bachelor's Degree or Higher ☐ Unemployment Rate (%) ☐ Median Age ☐ % Age 17 and Under ☐ % Age 65 and Older ☐ % Age 85 and Older
--	---	---

1. The CODAP dataset includes many variables associated with Texas counties (listed above). Which variables might show a correlation to % of People in Power Outages in 2021? Decide which variable you are most interested in investigating, and check the box next to it.

Accept all student choices. The examples below are based on the variable "income per person".

2. Why do you think the variable you chose might be correlated to the likelihood of losing power in February 2021?

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	Look for students to restate that they believe their variable is correlated to power loss , but not to attempt a mechanistic explanation.	Look for students to suggest a mechanism for power loss by making connections to human engineering decision-making or to natural causes.	Look for students to explain why their variable might be related to power loss by making connections to human engineering decision-making or to natural causes. Look for language that suggests uncertainty because correlation is not causation.
Example	Because I think more low-income people lost power.	Because people in wealthier neighborhoods pay higher taxes.	Because maybe the power companies didn't want to turn off the power in neighborhoods that had more money, because those people pay higher taxes and could get them fired, so that would mean that in wealthier neighborhoods, fewer people lost power.
Feedback/ What to Do	Write something like, <i>I'm curious, why do you think this?</i>	Write something like, <i>How would this cause a difference in who lost power?</i> Remind students that correlation is not causality, but that it can suggest interesting relationships that can be investigated in different ways.	Write something like, <i>Interesting theory!</i> Be cautious to validate the idea without indicating whether the explanation is supported by the data. Remind students that correlation is not causality, but that it can suggest interesting relationships that can be investigated in different ways.

Part 2: Formulate a Hypothesis

- Turn your variable into a hypothesis that **explains why some people in Texas lost power and some people did not** by completing the following sentence frame and circling the underlined word that describes the relationship you are predicting between the variables.

During the Texas power crisis of February 2021, people were more / less / just as likely to lose power in counties where the average income per person is higher.

Look for a hypothesis that follows from the ideas students had in Question 2.

4. If your hypothesis is well supported by the data, what do you predict the CODAP graph will look like? Make a rough sketch of your prediction on the axes at the right. Be sure to label the axes with the appropriate variables.

Look for students to draw a line or a series of dots with either a positive slope (if they circled "more" in Question 3), a negative slope (if they circled "less" in Question 3), or a flat slope (if they circled "just as" in Question 3).

Support students who are not yet making connections in seeing how their hypothesis will map onto this trend by writing something like, *You mentioned that you thought this would make people more likely to lose power. Is this what your graph shows?*



Part 3: Test Your Hypothesis

Go to <https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FbDWoSklKcv8T1sfwGva%2Ffile.json> to open the data set in CODAP. Drag the variable you chose from the data table onto the x-axis of the graph.

5. Look for patterns in the scatter plot. What pattern(s) do you see (if any)? How does this pattern compare to the prediction you made above?

Look for students to notice either a slight pattern (e.g., "it looks like the line goes down") or no pattern at all (e.g., "There is no apparent pattern"), and to relate this noticing to their prediction (e.g., "This is not what I predicted, because I thought there would be a line down").

The r^2 value on the line of best fit is known as the *correlation coefficient*. If r^2 is close to 1, the line is a very good fit, which means that variable helps us predict how many people lost power in a given county. If r^2 is close to 0, the line is not a good fit, and the variable you chose does not help us predict how many people lost power in a county.

6. Select the ruler icon in the upper right, and note that "Least Squares Line" is checked in order. Write the r^2 value given on the line of best fit for the variable you chose below.

$r^2 = .012$

7. Does the r^2 value calculated by the graphing program support your hypothesis? Why or why not?

"No, because my hypothesis was that higher income would mean lower percentage of people with power out, but if anything, it's the opposite, and also the coefficient is low, so there is almost no correlation."

8. Try looking for other correlations in the data by selecting other variables on the x-axis in CODAP. Record anything you notice below.

Accept all ideas.

9. What limitations might be introduced by the fact that our data is grouped by county? How might this affect our ability to see what happened in Texas?

"Maybe because it was grouped by county, we couldn't see details of different things that might have been happening within the counties."

Lesson 8 Teacher Reference

How to Create Electronic Exit Tickets

What are Electronic Exit Tickets?

These are short **formative** assessments that occur 2-3 times per unit, in between other assessments. They include items to check for understanding of lesson-level PEs, to make connections between content and students' lives, and to elicit information about their experiences and to help students reflect on their own progress in focal SEPs and CCCs. **They are built in Google Forms, but can be ported to any survey software.**

How to create Electronic Exit Tickets

In *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)* unit, the two Electronic Exit Tickets in this unit are found:

- at the end of Lesson 8;
- and at the end of Lesson 10.

Select the link for the Electronic Exit Ticket that corresponds with the lesson you are teaching.

<https://docs.google.com/forms/d/1lhV5AKCSuAfnQd6lIt6rVGf-v7z5TCLl6VUrrnZ5Jfg/copy>

<https://docs.google.com/forms/d/1Xp-dPusvOa59-ZFiyIO3ghf7j6rOHdNzQqGfRBsnjU4/copy>

Spanish versions are available here:

<https://docs.google.com/forms/d/1A-jBDRRMBhR2VhFCGB4nHiO26jiAXu8vaVdpAOLcpcl/copy>

https://docs.google.com/forms/d/1b5_n6JPXhFj8UDWx6P2sjEpFlu-ulCY_9jTxbBQgu4I/copy

Attending to Equity

Some students may benefit from completing the Electronic Exit Tickets on a printed version. Complete the steps below to create a copy of the Electronic Exit Ticket. Once you have created a copy in your own Google Drive, click on the 3 dots in the upper right side of the form next to the SEND button. This should give you an option to print a paper copy of the Electronic Exit Ticket.

When you select the link, it will ask you to make a copy in your own Google Drive.

Copy document

Would you like to make a copy of **Family and Friends MRE Survey?**

Make a copy



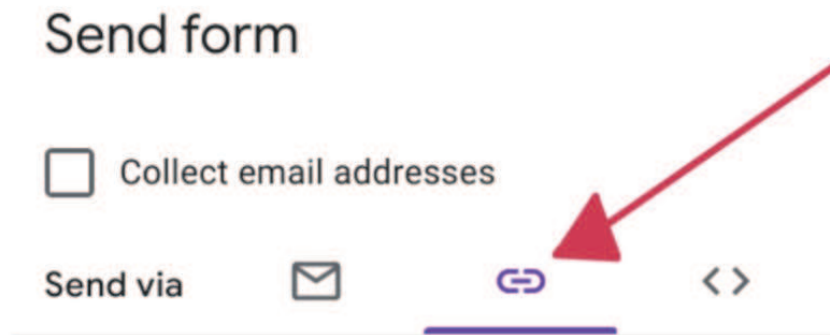
The student survey will open in your own Google Drive.



Select the “Send” button in the upper right corner to get a link to give to students.



In the “Send via” panel select the middle icon in order to choose to send the survey via a link.



Copy the link it provides you or select the “Shorten URL” box then copy the link. This second option creates a link that will be easier for students to type.

Link

<https://forms.gle/9YFjGS5FQhY3P7VR6>

☒ Shorten URL

Press Ctrl+C to copy

Cancel

Copy

Once people submit responses they will show up in your Google Form under “Responses”. Google will automatically provide you with some visualizations of these responses.

Questions

Responses

0 responses



Accepting responses 

Waiting for responses

If you want to see the data in a spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when people respond to the survey.

For each survey, you will need to repeat the process above. You can choose to make a copy of the survey for each of your classes or choose to have one survey for all your classes.

Lesson 8: Answer Key

L8 Electronic Exit Ticket Key

This electronic exit ticket addresses 3D elements associated with the lesson-level performance expectations from Lessons 7 and 8, which function together as a problematizing/putting-the-pieces-together routine for the first lesson set of the unit. This assessment is designed to make it easy to gather information about where your students are still struggling to put the pieces together.

The relevant lesson-level performance expectations are:

7.A Develop a model showing how insufficient supply entering the system could lead to reduced energy transfer into certain communities in Texas when the temperatures dropped, resulting in buildings losing power. (SEP: 2.3; CCC: 5.2, 5.3; DCI: PS3.B.4)

7.B Develop and test a correlational hypothesis to investigate trade-offs inherent in making decisions about energy, and then consider limitations on this analysis to motivate seeking information about patterns at a smaller grain size. (SEP: 1.6, 4.2, 4.3; CCC: 2.1, 3.3; ETS1.B.1)

8.A Integrate quantitative information, visual information, and audio (or text) to define some of the challenges and trade-offs associated with a drop in energy supply driven by cold weather, and consider additional trade-offs associated with making energy decisions. (SEP: 8.2; CCC: 5.2, 5.3, Science Addresses Questions About the Natural and Material World; DCI: ETS1.A.2, ETS1.B.1)

The elements of these lesson-level performance expectations assessed in this exit ticket are:

3D Elements Addressed in the Assessment	1	2	3	4	5
Using Mathematics and Computational Thinking: Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.		X			
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.	X				
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.	X				
Cause and Effect: Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.		X			
Patterns: Patterns observable at one scale may not be observable or exist at other scales.					X
Science Addresses Questions About the Natural and Material World: Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. Science knowledge indicates what can happen in natural systems--not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.				X	
ETS1.B.1 Developing Possible Solutions: When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)			X		
PS3.B.4 Conservation of Energy and Energy Transfer: The availability of energy limits what can occur in any system. (HS-PS3-1)	X				

Question 1

100 units of energy are supplied to a power grid by a power plant; 85 of those units are distributed in the community to meet demand. What probably happened to the other 15 units of energy that were supplied by the power plant? (CCC: 5.2, 5.3; DCI: PS3.B.4)

- They were returned to the power plant to be recycled.
- **They were transferred to the surroundings from power lines as heat.**
- They were destroyed in the process of transport through power lines.

What to look for:

The correct answer is: **They were transferred to the surroundings from power lines as heat.**

What to do: Encourage students to look back at their Progress Trackers and energy transfer models for examples of energy leaving the system (energy outputs).

Question 2

A teacher noticed that at the start of the school year, many students in the class were sunburned. The teacher decided to collect data about how sunburned the students were on a scale of 1-10, and how much ice cream the students had consumed on average over the summer. **The teacher's hypothesis was that ice cream is so delicious that it causes students to forget to put on sunscreen.** The student organized the data and put it into CODAP, shown below. R^2 for the data is .831.

Which conclusion is supported by the data? (SEP: 4.2 ; CCC: 2.1)

- **The data show a strong correlation between the two variables, but do not show that ice cream causes students to forget.**
- The data show no correlation between the two variables, and do not support the teacher's hypothesis.
- The data show a correlation between the two variables, proving the teacher's hypothesis to be correct.
- The data show that students who eat more ice cream are less sunburned, disproving the teacher's hypothesis.

What to look for:

The correct answer is: **The data show a strong correlation between the two variables, but do not show that ice cream causes students to forget.**

What to do: Encourage students to revisit *Texas County Data Analysis*, and their Progress Trackers from Lessons 7 and 8.

Question 3

People make decisions every day, some big and some small. **What is a decision you or someone you know has had to make that required making trade-offs? What were the trade-offs involved, who did they affect, and why?** (DCI: ETS1.B.1)

What to look for:

Look for students to describe any situation involving a trade-off, and be able to describe what the trade-off is between.

What to do: Encourage students to revisit their Progress Trackers from Lesson 8. Check in with students who suggest interesting examples, and ask them if you could share their ideas. Use student-generated ideas to support thinking about trade-offs in Lessons 9-11.

Question 4

Electricity is a resource that can fluctuate in supply. **Sometimes it is easy to generate enough electricity. At other times, it is difficult to meet demand, and electricity is scarce.** Think of another resource that is sometimes easy to get and sometimes scarce. What would you do if you knew that resource was going to be hard to get soon? (NOS: Science Addresses Questions About the Natural and Material World)

What to look for:

Look for students to suggest any number of examples related to conserving a resource, for example by:

- stockpiling (resource storage, e.g., hoarding toilet paper during a pandemic)
- accessing the resource before others can get their hands on it (e.g., waiting in line to purchase a new toy or gaming system)
- reducing demand (e.g., using less water during a drought)

What to do: Highlight ideas about stockpiling resources and come back to them in Lesson 9. Use these ideas as an analogy for motivating battery storage. If students need support here, suggest specific situations in which a resource might be sparse, such as during a toilet paper shortage or a drought.

Question 5

How has thinking about the science of the Texas crisis at multiple scales helped us make progress on figuring out what happened in 2021, and how we could prevent blackouts in our community? (CCC: 3.3)

What to look for:

Look for students to mention one or more of the following examples, or something else they noticed related to scale that we have talked about:

- The microscopic scale of electrons in a wire helped us understand energy transfer through wires.
- The macroscopic scale of the generator system helped us understand how energy from a source like natural gas or wind becomes electrical energy.
- The smaller scale of satellite data versus county-level data helped us understand patterns in who lost power.

What to do: Ask students to look through their Progress Trackers for examples of modeling or explanations at different scales. Once they find an example, ask them why we modeled at that scale rather than at another scale. Do not expect students to be able to name these various scales, but rather to recognize that by zooming in or out, we figured out more than if we had stayed at a single scale.

Lesson 9: Answer Key

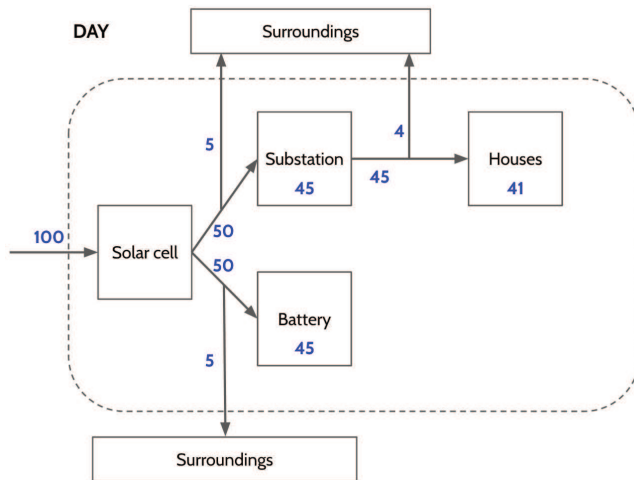
Modeling Reliability Key

Building toward: 9.A Develop an energy transfer model to predict the stability in the distribution of electric energy when batteries are present and absent from the system. (SEP: 2.3; CCC: 7.4; DCI: PS3.B.1, PS3.B.4)

Complete 2 energy transfer models to show how adding a battery to a system could make it more reliable. In the **first model**, represent the energy transfer in a system **before** the energy supply drops. In the **second model**, represent the energy transfer in the same system **after** the energy supply drops. In both models, show how much energy will be transferred between the components of the system, and how much energy will be available to the community. You can make the following assumptions:

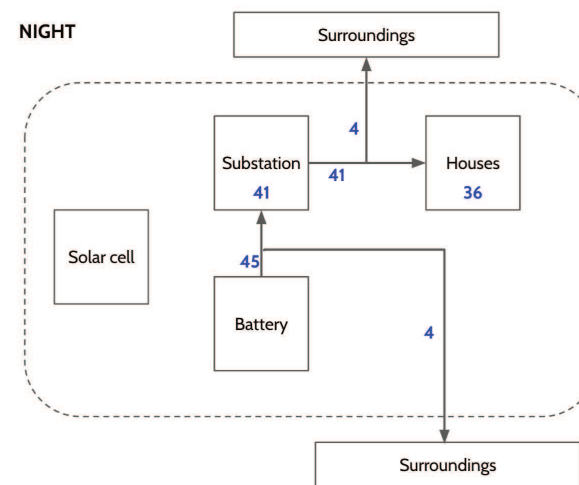
- Assume that when the power plant is generating power, it produces 100 units of energy.
- Assume that 10% of the energy transferred between any 2 components is lost to the surroundings.
- Assume that the energy demand is the same before and after the energy supply drops.
- You do not need to describe the mechanism for energy transfer for each arrow.

Energy transfer model **before** energy supply drops



This model should include some percentage of the energy going to the battery.

Energy transfer model **after** energy supply drops



If the energy reaching the homes in this model is different from the energy reaching the homes in the model on the left, look for students to explain the meaning of this difference. In this example, the homes are getting most of the energy they need, but not all.

Based on your models, why would adding a battery to the system affect its reliability?

Adding a battery will make this system more reliable because it can supply some of the energy that the homes connected to the grid will need when the power supply drops. Without the batteries, there would be no power reaching these homes. Even if the supply drops a small percentage, the energy stored in the batteries would allow power companies to fill the gap between energy supply and demand.

If students do not model directional energy transfer, but still represent the system by drawing a battery connected to a power plant and/or a community, they may have a **foundational understanding**. Support these students by giving them small sticky notes to label the systems in their diagram, and then ask them to use a thick marker to show the way energy transfers through the sticky note systems.

If students model the battery as part of a linear system, they are demonstrating a **linked understanding**, but may not yet be organizing ideas. Support these students by asking questions such as:

- *Does all the energy from the power plant need to pass through the battery before it gets to the community? Is this the most efficient way to set up the system?*

If students model the system correctly but struggle to quantify energy in the system, they are demonstrating a **linked understanding**, but may not yet be organizing ideas. Consider providing these students with 10 tokens (e.g., pennies or beads) to represent 100 units of energy. Ask them to trace these tokens through the system, and deposit them where they will end up. Wherever there is an arrow, 1 token needs to leave the system.

Testing Battery Storage Solutions Key

Could battery systems have prevented the blackout in Texas?

We can measure the difference between supply and demand for each hour of the blackout in Texas. These values vary from 10,000 MWh to 40,000 MWh, but the average value is about a 25,000 MWh difference. The blackout lasted for about 100 hours. Multiplying 100 hours by about 25,000 MWh of energy each hour gets us:

$$100 \text{ hours} \times 25,000 \text{ MWh/hour} = 2,500,000 \text{ MWh of total energy}$$

The largest single battery storage system built so far in the United States is in Moss Landing, California. It has a storage capacity of 1,600 MWh, and was built by a Texas company in 2020 for about \$400 million.

If we consider the Moss Landing system as 1 unit, we can estimate how many of these units would be needed to store enough energy to prevent a situation like the energy crisis in Texas in February 2021. We need to divide the total amount of energy (2,500,000 MWh) by the energy that 1 unit can store (1,600 MWh):

$$\frac{2,500,000 \text{ MWh}}{1,600 \text{ MWh per system}} = 1,562 \text{ systems}$$

If each of these systems costs \$400 million, we can multiply by 1,562 systems to estimate how much it would cost to implement this design solution:

$$1,562 \text{ systems} \times \frac{400 \text{ million dollars}}{1 \text{ system}} = 625,000 \text{ million dollars (or 625 billion dollars)}$$

There are often multiple ways to set up a computation. We can also solve this problem using ratios to combine both of these steps into a single step:

$$2,000,000 \text{ MWh} \times \frac{400 \text{ million dollars}}{1,600 \text{ MWh}} = 2,000,000 \times 400 \div 1,600 = 500,000 \text{ million dollars}$$

If we divide this number by the total population of Texas (30,000,000 people), we find that it would cost \$20,833 per person to install enough batteries to implement this solution. That seems too expensive. But maybe there is another energy storage solution that would be more affordable.

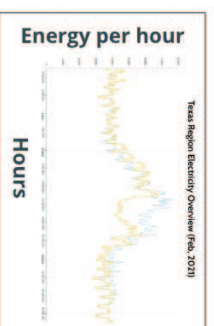
Solve the problems below to evaluate energy storage solutions to determine their feasibility for preventing an energy crisis.

Evaluating Additional Energy Storage Solutions

Question 1. Another major battery manufacturer sells industrial-sized lithium-ion batteries with a storage capacity of about 4 MWh for only \$2 million each. How much would it cost to install enough of these units to have prevented the power crisis in Texas? Express your answer using meaningful units.

$$\frac{2,500,000 \text{ MWh}}{4 \text{ MWh per system}} = 625,000 \text{ systems}$$

$$625,000 \text{ systems} \times \$2 \text{ million} = 1,250,000 \text{ million dollars (or 1,250 billion dollars)}$$



$$\frac{\text{Energy}}{\text{Hour}} \times \text{Hours} = \text{Energy}$$



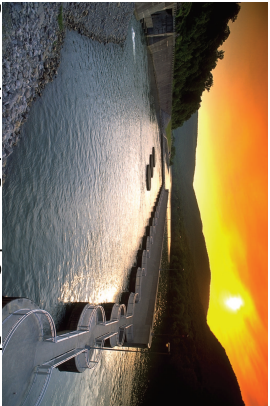
1 system

(Students could also calculate this in one step. Accept both methods.)

Question 2. Is this a more cost-effective solution than the Moss Landing system? Why or why not?

No, because it's even more expensive than the Moss Landing system.

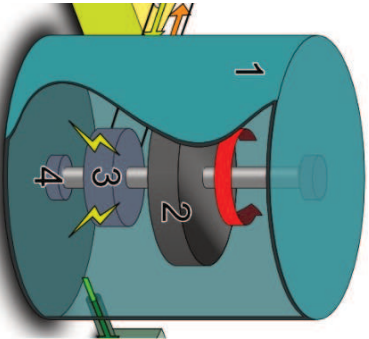
Lubbock, Texas has a population of about 200,000 people. Estimating from statewide values, the total difference between energy supply and demand in Lubbock during the blackout was about 16,000 MWh. The community of Lubbock is considering installing batteries to improve the reliability of their grid, which is increasingly dependent on wind. They are also considering 2 alternative storage solutions that do not require chemicals: a pumped storage system and a flywheel.



Raccoon Mountain Pumped-Storage Plant
Tennessee Valley Authority

Pumped storage systems have been in use for many decades, often combined with hydroelectric dams and reservoirs. Energy is transferred to a pump, which pushes water uphill against gravity. This water is kept in the upper reservoir as long as the energy isn't needed. To use the stored energy, the water is released to flow through a turbine, which spins a generator as the water flows downhill.

A **flywheel** stores energy in motion by rotating a large, heavy cylinder (2) inside a case (1). Energy is transferred to a motor (3), which makes the cylinder spin very, very fast. High-speed ball bearings are used to reduce friction (4). The cylinder keeps spinning as long as the energy isn't needed. To use the stored energy, a generator is engaged--the cylinder slows down as it pushes the generator (3), transferring kinetic energy to electrical energy.



A flywheel--battery model Tosaka, CC BY 3.0

	Energy Storage	Total Cost	Land Area Used	Efficiency
Moss Landing Li-Ion Storage System	1,600 MWh	\$400 million	15 acres	90%
Single Battery Li-Ion Storage System	4 MWh	\$2 million	0.02 acres	92%
Pumped Hydro-Gravity Storage System	8,000 MWh	\$480 million	400 acres	85%
Flywheel Kinetic Storage System*	0.25 MWh	\$50,000	5 acres	90%
*The largest flywheel storage system in the United States is in Stephentown, New York.				

Question 3. Use data from the table above to calculate the cost of using each solution to store the 16,000 MWh of energy that would have been needed to prevent blackouts in Lubbock during the Texas storm. Label each solution clearly, and show your calculations using meaningful units.

Moss Landing
16,000 MWh x 400 million dollars = 4,000 million dollars
1,600 MWh

Single Battery
16,000 MWh x 2 million dollars = 8,000 million dollars
4 MWh

Pumped Storage
16,000 MWh x 480 million dollars = 960 million dollars
8,000 MWh

Flywheel
16,000 MWh x 50,000 dollars = 3,200 million dollars
.25 MWh

Question 4. Choose the solution that you would recommend based on total cost. How much land area would this solution use? Clearly indicate which solution you have chosen, and show your calculations using meaningful units.

Pumped storage is the cheapest option. We would need only 2 of these units.
2 units * 400 acres = 800 acres

Some of the energy stored in a battery will be lost to the surroundings. The percentage of energy lost between input and output is called the *efficiency*. We can think of efficiency as a ratio:

$$\frac{\text{energy output from storage}}{\text{energy input to storage}} = \text{efficiency}$$

For example, an efficiency of 60% could be expressed as:

$$\frac{60 \text{ MWh output}}{100 \text{ MWh input}} = .6 = 60\%$$

If we know the efficiency of a system, and the output that we want, we can use algebra to solve for the input we need.

Question 5. For each of the solutions above, what total storage capacity would Lubbock need to install to achieve 16,000 MWh of useful energy output, assuming the efficiencies listed in the table? Label each solution clearly, and round to the nearest MWh.

Moss Landing

$\frac{16,000 \text{ MWh output}}{\text{X input}} = .90$

$X = 16,000 \text{ MWh} / .9 = 17,778 \text{ MWh}$

Single Battery

$\frac{16,000 \text{ MWh output}}{\text{X input}} = .92$

$X = 16,000 \text{ MWh} / .92 = 17,391 \text{ MWh}$

Pumped Storage

$\frac{16,000 \text{ MWh output}}{\text{X input}} = .85$

$X = 16,000 \text{ MWh} / .85 = 18,824 \text{ MWh}$

Flywheel

$\frac{16,000 \text{ MWh output}}{\text{X input}} = .90$

$X = 16,000 \text{ MWh} / .9 = 17,778 \text{ MWh}$

Question 6. Do any of the solutions in the table seem useful and feasible for the people of Lubbock? Why or why not?

Pumped hydropower seems like it might work. It is not as expensive. But it also takes up a lot of space.

Lesson 9: Answer Key 3

Engineering Design Tracker Examples

Engineering Design Tracker

Lesson #	What are the new science ideas that we figured out that might affect our community solutions?	How could engineers designing a power grid for a community apply these ideas in practice?	What constraints might make it hard for engineers to apply these ideas?
3	<i>If there is a break in a circuit, energy will not flow. If a shorter path is created, the energy will flow down that path. An interruption in charge flow-through may be due to a break in the circuit (maybe a tree falls on a wire) or a short circuit (maybe a line falls on another line, or a tree connects it to the ground). This prevents the energy from transferring to our communities. This could be caused by a severe storm that knocks down trees.</i>	<i>Engineers have added insulation to wires to prevent short circuits caused by animals, like squirrels.</i> <i>Engineers have raised power lines higher off the ground to keep squirrels away.</i> <i>Engineers have moved the power lines below ground to prevent damage from animals, ice, wind, and trees.</i>	<i>The biggest constraint to moving power lines below ground is cost. It's over 10 times more expensive to install power lines underground versus aboveground.</i> <i>Another constraint is access to the power lines. It is more expensive to repair underground power lines because they are harder to access.</i> <i>Underground power lines can still be damaged by flooding or earthquakes.</i>
6	<i>Energy is lost over a wire. A thicker wire means less energy loss. The cold doesn't affect energy loss very much.</i>	<i>We could use really thick wire.</i> <i>We should also not let the wires get too hot if possible, maybe by using less insulation.</i> <i>We should also build power plants as close to our communities as possible.</i>	<i>Using less insulation could be dangerous. Also, thick wire is probably more expensive, and building closer power plants means more power plants, which could be way more expensive, and could annoy people in the neighborhoods where the plants would be built. Also, maybe the resources that the plants need, like water, wind, or coal, aren't close to the community.</i>
8	<i>In Texas, there was an imbalance of energy inputs and outputs that led to the power outages. People were using a lot more energy because it was cold and they needed heat. And also, power plants shut down because their parts froze.</i>	<i>Engineers in other places have winterized windmills and natural gas lines so they don't freeze.</i>	<i>It is expensive to winterize equipment, and it can be hard to convince people to spend that money in places where it doesn't get cold very often.</i>

?	Batteries and other storage solutions can store energy for later.	Engineers could build giant batteries.	There are a lot of constraints: for example, environmental impact, social impact, and safety. Some mechanical batteries are not as bad for the environment as chemical batteries, so they hold a lot of promise.
---	---	--	--

Lesson 10: Answer Key

L10 Electronic Exit Ticket Key

This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations from Lessons 9 and 10. This assessment is designed to make it easy to gather information about where students are still struggling to apply certain practices in the context of engineering.

The relevant lesson-level performance expectations are:

9.A Develop an energy transfer model to predict the stability in the distribution of electric energy when batteries are present and absent from the system. (SEP: 2.3; CCC: 7.4; DCI: PS3.B.1, PS3.B.4)

9.B Apply ratios, rates, percentages, and unit conversions to calculate the costs and land area of use of a design solution to evaluate its feasibility for preventing an energy crisis like the one in Texas in 2021. (SEP: 5.5; CCC: 3.1; DCI: ETS1.B.1; PS3.D.1)

10.A Analyze data generated by interviews with community members to specify criteria for success related to energy solutions, such as monetary cost, safety, and reliability, and weigh cost/benefit trade-offs related to social, cultural, and environmental impacts. (SEP: 4.6; CCC: Influence of Science, Engineering, and Technology on Society and the Natural World; DCI: ETS1.B.1)

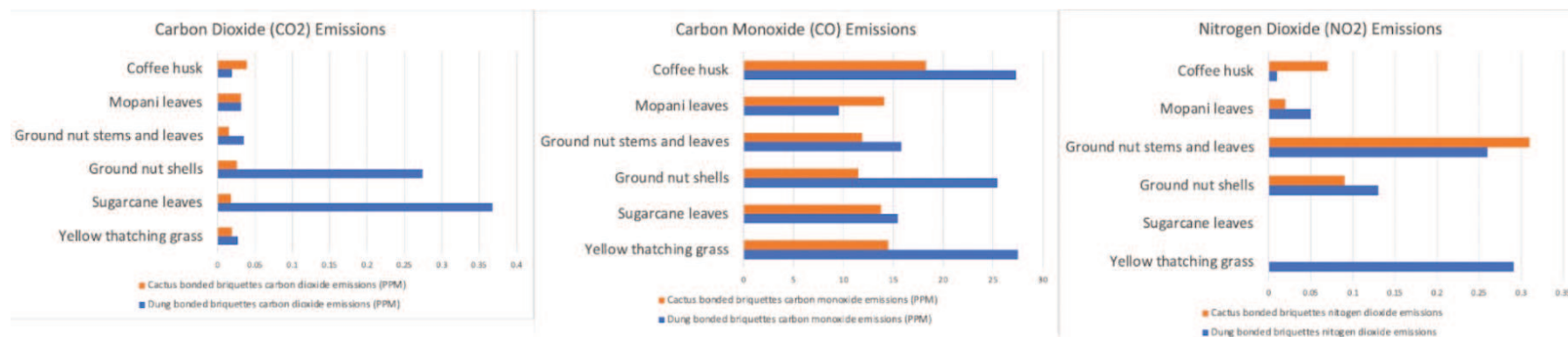
The elements of these lesson-level performance expectations assessed in this Electronic Exit Ticket are:

3D Elements Addressed in this Assessment	1	2	3	4	5
4.6 Analyzing and Interpreting Data. 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.	X	X			
5.2 Using Mathematics and Computational Thinking. Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.			X		
6.5 Constructing Explanations and Designing Solutions. Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.				X	
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. (HS-ETS1-1) (HS-ETS1-3)				X	X
ETS1.B.1 Developing Possible Solutions: When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	X				
PS3.D.1 Energy in Chemical Processes and Everyday Life. Although energy cannot be destroyed, it can be converted to less useful forms--for example, to thermal energy in the surrounding environment. (HS-PS3-3) (HS-PS3-4)			X		

Question 1

A scientific study compared the combustion and emissions of loose biomass formed into small bricks called briquettes. The scientists compared six types of plant matter briquettes that were bonded together with cactus, along with the same six types of plant matter briquettes bonded together with cow dung.

Their results are shown below. Orange lines represent the emissions from the cactus-bonded briquettes. Blue lines represent the emissions from the dung-bonded briquettes.



If the **most valued criterion** facing a community is **lowering carbon dioxide emissions**, which type of briquette would you recommend? (SEP: 4.6; DCI: ETS.B.1)

- Cactus-bonded coffee husk
- Cactus-bonded ground nut stem and leaves
- Dung-bonded sugarcane leaves
- Dung-bonded coffee husk
- Not enough data to make this recommendation

What to look for: The correct answer is: Cactus-bonded ground nut stem and leaves.

What to do: Ask students what graph they should be looking at if the most valued criterion facing a community is lowering carbon dioxide emissions. Then ask them whether they think the line should be small or large. Find time to work alongside students to use the identify and interpret strategy to scaffold interpretation of the graphs.

Question 2

In sub-Saharan Africa, access to electricity is very limited. As a result, the people living there increasingly rely on burning wood as a source of energy for cooking and space heating. This exposes families to diseases such as chronic obstructive pulmonary disease (COPD). COPD mostly affects women and young children, because they spend more time inside by the stove. Gases like carbon monoxide and nitrogen dioxide are thought to contribute significantly to the development of COPD.

Which type of briquette would you recommend for a community in sub-Saharan Africa who wants to address the problem of rising COPD rates? (SEP: 4.6; DCI: ETS.B.1)

- Cactus-bonded coffee husk
- Cactus-bonded ground nut stem and leaves
- Dung-bonded sugarcane leaves
- Dung-bonded coffee husk
- Not enough data to make this recommendation

What to look for: The correct answer is: Dung-bonded sugarcane leaves.

What to do: This question is not as direct as the first, as it requires students to first connect COPD to carbon monoxide and nitrogen dioxide, and then compare multiple graphs to minimize both these emissions. Mopani leaves would also be a valid response, which is why we did not include it as an answer. Validate this idea if students are confused, and ask them to choose the next-best option. Ask students what graphs they should be looking at if the most valued criterion facing a community is lowering rates of COPD. Then ask them whether they think the line should be small, or large. Consider asking students to assign values to the bar graphs, and sum them for a more precise measure. Find time to work alongside students to use the identify and interpret strategy to scaffold interpretation of the graphs.

Question 3

Biomass fuel is highly efficient when used for electricity generation, at about 90% maximum efficiency. This means that 90% of the energy stored in the biomass will reach the electric grid as usable energy. But when used to heat homes, biomass is significantly less efficient, at about 20% maximum efficiency.

The scientists note that the dung-bonded briquettes were more dense, and thus had higher efficiency, and provided more heat when burned, for a longer time. Assume a family uses a briquette of dung-bonded biomass containing 1,500 megajoules (MJ) of stored energy to heat their home. What calculations would you use to calculate the energy from the briquette (in MJ) that will be used to keep the family warm? (SEP: 5.2; DCI: PS3.D.1)

- $1,500 \text{ MJ} - 20 \text{ MJ} = 1,480 \text{ MJ}$
- $.8 * 1,500 \text{ MJ} = 1,200 \text{ MJ}$
- $20 * 1,500 \text{ MJ} = 30,00 \text{ MJ}$
- $0.2 * 1,500 \text{ MJ} = 300 \text{ MJ}$

What to look for: The correct answer is: $0.2 * 1,500 \text{ MJ} = 300 \text{ MJ}$

What to do: Encourage students to revisit the *Testing Battery Storage Solutions* handout from Lesson 9, and the *Energy Source Cards* from Lesson 4 that define efficiency. Students may need support from you in recalling how to represent percentages as decimals, and why. Consider working with a math teacher if this level of support is required.

Question 4

Articulate a potential trade-off a community might face if they are choosing between which type of briquette to use. (SEP: 6.5; ETS: Influence of Science, Engineering, and Technology on Society and the Natural World)

What to look for: Look for students to articulate a trade-off between two criteria or constraints. Some examples:

- The dung-bonded briquettes have the highest emissions overall, but they are more efficient. There is a trade-off between emissions and efficiency.
- The sugarcane leaves have the lowest COPD-causing toxins, but they have very high carbon dioxide emissions. There is a trade-off between environmental harm and human harm.

What to do: Ask students to look back at the trade-offs that they articulated from the reading at the start of Lesson 10 for support.

Question 5

Why do you think the analysis of costs and benefits is such a critical aspect of decisions about technology? (ETS: Influence of Science, Engineering, and Technology on Society and the Natural World)

What to look for: Accept all ideas. Some ideas students might have:

- Making decisions can have impacts on the world that we don't think about.
- Different communities have different criteria and constraints.
- It's important to think about things other than how much something costs in money.

What to do: Ask students to look back at the trade-offs that they articulated from the reading at the start of Lesson 10 for support. Ask students to look at their Engineering Design Tracker and *Decisions Matrix* for ideas about how we have applied costs and benefits to our thinking.

Lesson 11: Answer Key 1

Design Challenge Key

Building Toward 11.A Define a problem related to the challenge of improving our electrical grid, and then design, evaluate, and refine a solution, taking into account social, cultural, and environmental impacts (both intentional and unintentional), based on results from a computational model, scientific knowledge we have figured out over the unit, weighted criteria, and trade-off considerations. (SEP: 1.8, 2.6, 6.5, DCI: ETS1.A.2, ETS1.B.2, ESS3.A.2, ETS1.B.1; CCC: 1.3)

A “mock-up” of example student slide presentation is included in the Lesson Folder, titled *Design Solution Exemplar*. This work is not intended to show what we think students should produce, as this will depend entirely on your students and the time they spend (in and/or out of class) to complete their work. The responses in this key are based on that example.

Questions 1 and 2 can be used as a formative assessment, to get a sense of where each student is in their understanding and their writing ability. If you notice that a group of students has struggled to complete these questions, then they are likely to struggle even more on the rest of the assignment. However, if you can support all students to write thoughtful answers to Questions 2 and 3, they will have more to contribute to their group for Question 5.

The rubrics for Question 2 and 3 are set up to help you support students who have some foundational pieces to reach linked understanding, and to support students who have reached linked understanding to organize this understanding. OpenSciEd does not recommend openly targeting and isolating any students from their peers. Instead, consider giving students clear feedback on where they stand, and give them the choice to participate in a more targeted intervention related to each specific question. Alternatively, if your school offers students time outside class to work more closely with teachers or tutors, such as “office hours”, consider intentionally scheduling multiple students for this time, so you can work with them together.

3D Elements Addressed in This Assessment		2	3	4	5
1.8 Asking Questions and Defining Problems: Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations		X		X	
2.6 Developing and Using Models: Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.			X		
6.5 Constructing Explanations and Designing Solutions: Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.			X	X	X
ETS1.A.2 Defining and Delimiting Engineering Problems: 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. (HS-ETS1-1)			X		X
ETS1.B.2 Developing Possible Solutions: Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)			X		
ESS3.A.2 Natural Resources: All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.		X			
ETS1.B.1 Developing Possible Solutions: When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)		X	X		X
1.3 Patterns: Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.			X		X

Introduction

Every year, politicians, voters, residents, and power company employees make important decisions about the energy future of your community. You have the power to speak up about how to move toward a more reliable energy infrastructure that meets the community's needs. Develop a community plan that you can use to guide your decision-making. Move through the steps below to:

- 1. Establish trade-offs, criteria, and constraints.
- 2. Develop a plan you would like to advocate for to improve our electricity infrastructure to increase reliability and meet our community's needs.
- 3. Communicate your plan to the class, or to other interested parties.

Part 1: Establish trade-offs, criteria, and constraints

Question 1. As a group, decide how you will weigh interested party opinions to address **trade-offs** between various energy sources and grid storage solutions. You do **not** need to prioritize the criteria that were the most popular, but if you choose to diverge from interested party values, you will need to explain why you made that choice.

- a. Add these weights to your Decisions Matrix using the conventions your class agreed on.
- b. Use your weighted Decisions Matrix to identify and articulate the top **criteria** that will tell us whether the solution is successful. You will need to choose reliability as 1 criterion, and then up to 2 additional criteria that your analysis revealed. List your top criteria here, and then add numbers to indicate which is the most important to you.

Criterion	Ranking (1 is most important)
High Reliability	1
Low Cost	3
Low Carbon Emissions	2
High Local Jobs	4

c) Explain your decision-making below. Make sure to include how you took interested party opinions into account, and why you did it that way.

We used the interviews that each of us did with our family members because all of them identified high reliability in their top 2. Most people had low carbon emissions in their top 3 also, and one person had low cost as their highest priority. We agreed that high reliability had to be number 1, but we discussed for a while whether carbon or cost should be second. We ended up taking a vote because that seemed fair.

Part 2: Prepare your community plan

Question 2. All forms of energy production and other resource extraction have **economic, social, and environmental benefits, as well as costs and risks**. Cite evidence from our readings, data analysis, and the Energy Grid Calculator to identify and explain the benefits, costs, and risks of your region's current grid solution.

Rubric for Q2:

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	Look for: Define a problem by Identifying economic, social, or environmental benefits and costs.	Look for: Define a problem by Identifying and explaining economic, social, and environmental benefits, costs, and risks associated with energy sources currently used in our local region's electrical system.	Look for: Cite empirical evidence to define a problem by Identifying and explaining economic, social, and environmental benefits, costs, and risks , in order to evaluate energy sources currently used in our local region's electrical grid. Empirical evidence is in the form of quotes from readings, as well as specific values from the Energy Grid Calculator and the <i>Energy Source Statistics</i> .
Example	Benefits: High reliability, because the 2 reliability numbers are green. Costs: High carbon emissions, because the carbon number is red.	Benefits: High reliability is a benefit because so much energy comes from natural gas, which can be increased or decreased to match demand. Costs and Risks: High carbon emissions are a risk because natural gas emits lots of carbon, which contributes to climate change. Higher global temperatures will make severe weather events like the Texas storm more likely.	Benefits: According to the Energy Grid Calculator, our grid could meet 90% of demand during a severe winter storm. If wind and solar drop to zero, all citizens could get the electricity they need for unlimited hours, assuming gas fuel doesn't run out. Costs and Risks: Our grid emits about 4,000 kg per person per year, which is much more than we will need in order to reach "net-zero" carbon emissions by 2050. Carbon emissions and climate change have huge effects on the planet, including more extreme weather events. Also, most gas comes from fracking, which "often releases pollutants into the water, which can end up in the water supply for both humans and animals." Our current grid is unsustainable because the carbon emissions of the sources we rely on are much too high. Our current carbon emissions from electricity alone are 5 times what they should be if we are trying to reach net-zero carbon emissions. We are not considering the huge risks of global impact of climate change, therefore we are putting our whole way of life at risk.

Feedback	Linking:	Organizing:	Extending:
	First, recognize the positive behavior of students who identified specific evidence in their answer. Ask them to build on this by giving more specifics. Say, <i>Great job identifying specific details from the color of the Energy Grid Calculator. To build on this, first, explain why those colors came up. For example, why isn't the "Maximum Supply" value red for our current grid? Why is that important?</i> To help students focus on reliability, ask them to extend this evaluation by considering how the system would respond during an energy crisis. Say, <i>Great job using class ideas to describe good and bad things about our grid. Try to imagine what this could mean in the future. What might happen to our current grid if (describe a potentially negative event)? Why do you say that?</i> Provide sentence frames for students who struggle to put their thoughts into words: • "(High/Low) ____ is a benefit because _____. (High/Low) ____ is a cost because _____. " • "One good thing about our current grid is _____. When (describe a potentially negative event), (describe a positive logical outcome) because _____. " • "However, one bad thing about our current grid is _____. (Describe a negative logical outcome) because _____. "	Encourage students to make their evidence more specific and relevant, by using more specific values and quotes from our reliable sources. Ask them to consult their copy of the Energy Grid Calculator, and insert values and quotes into parts a and b.	To bridge to Q3, challenge students to think about what criteria our current grid is prioritizing, and why. To push students to make stronger quantitative connections to our sources of evidence, ask them to connect the values given on <i>Energy Source Statistics</i> to the makeup of your current grid. Ask them to use those values to predict what would happen to the values given in the calculator if different energy sources were demolished. They can then test those predictions. Say, <i>What do you think would happen to the global life cycle land use if you demolished a coal plant? Why is this? What does the change in that number actually represent in the real world?</i> Also, ask students to probe the details given in the calculator to investigate what they mean, and whether they seem valid. They can click the "Current CO2" link in the carbon emissions box, and input their regional information to see another estimate of carbon emissions per person per year. This value will likely be similar to, but not identical to, the value predicted by the calculator. Say, <i>Why might one model give us a different value for carbon emissions than another model? Which model do you trust more, and why? Can you ever rely 100% on the predictions given by one model?</i>

Question 3. The Energy Grid Calculator is a computational model that can be used to aid in the engineering design process. Refine an engineering solution in your copy of the Energy Grid Calculator to reflect the priorities of the interested parties you interviewed. Then summarize in words the changes you made to your region's current grid solution. In your work, make sure to:

- Describe changes:** Describe a few changes to the current grid your group made in your Energy Grid Calculator design solution.
- Explain priorities and trade-offs:** Identify priorities you focused on from the interested parties you interviewed. Analyze the trade-offs in your design solution by describing and explaining its benefits and costs, locally and globally. If you tried a few different solutions, describe any patterns you noticed across these solutions that helped you prioritize.

Rubric for Q3:

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	Look for: Use a computational model to create an electric grid solution idea, and determine how this solution idea might impact specific priorities, locally or globally.	Look for: Use a computational model to generate data to improve the local grid system to determine which meets priorities related to global challenges that have manifestations in local communities.	Look for: Use a computational model to generate data to analyze patterns in the predicted performance of electric grid solution ideas, testing different ways to improve the local grid system to determine which best meets priorities related to global challenges that have manifestations in local communities.

Example	a) Changes: We demolished 1 coal plant and 2 gas plants. We replaced them with 1 nuclear plant and 50,000 solar. b) Priorities and Trade-offs: My family prioritized global impact and local impact. Reducing carbon will help stop climate change, which has a bad global impact. Also, building a nuclear plant will create jobs at the plant, which is a good local impact.	a) Changes: We demolished 1 coal plant and 2 gas plants. We replaced them with 1 nuclear plant, 50,000 rooftop solar systems, and 250 batteries. b) Priorities and Trade-offs: All three of the people we interviewed had carbon emissions in their top 3 priorities, so we did that. Using nuclear and solar instead of coal and gas reduces carbon emissions from 4,200 to 1,800 because nuclear and solar are carbon-neutral. This could reduce jobs of people who work in gas, but those jobs aren't a priority for the people we interviewed. Originally we had all solar panels, but we saw that reliability was terrible because solar panels can't transfer energy at night, and reliability was another top priority. We had to add a nuclear plant and some batteries to solve this. The nuclear plant transfers a lot of energy to the grid all the time. The batteries store energy during the day, and then transfer that energy to the grid at night to increase reliability for people here in our region. But the fuel and the waste can cause cancer. There was a big spill near a Navajo reservation, and this could happen again if we're not careful.	a) Changes: We demolished 1 coal plant and 3 gas plants. We replaced them with 500 wind turbines, 500,000 rooftop solar systems, and 2 pumped storage facilities. b) Priorities and Trade-offs: Everyone we interviewed said that carbon emissions was one of their top 2 priorities. But my grandma was the only one who said cost was her most important priority, so my group ignored it. They said it wasn't possible to make a reliable grid without using nuclear power, but I was able to make a cheaper solution by using pumped storage instead of lithium-ion batteries. This increased reliability, decreased cost, and cut carbon emissions. I noticed that all the renewable sources required some kind of storage technology, because otherwise they are too unreliable to meet our energy needs. But all the plants that used fuel had huge negative impacts, both locally and globally. Pumped storage is actually a really good solution to use instead of chemical batteries. The local impact of cobalt mining is really dangerous for the people involved, and even though it's not local to us here, it still matters. In contrast, pumped storage basically requires a giant construction project, which would have a positive local impact because it would create jobs building and maintaining that facility. But pumped storage is only possible if we can find an area that could potentially work, and even then it could have huge effects on the environment near that facility. In my opinion, this is worth the lower cost if we can use it to lower carbon emissions.
---------	--	---	--

Feedback	<i>Linking:</i> Ask students to access the following: 1) Their team's copy of the Energy Grid Calculator, to help identify specific changes they chose to implement. 2) Their interested parties interview sheet, with priorities identified. 3) A collection of the jigsaw readings from L10. It may help to prioritize a common reading that is relevant to their current grid, to use as an example with a larger group of students. Say, <i>What were the top priorities your group identified from your interviews? What is one way that your grid calculator solution reflects these priorities?</i>	<i>Organizing:</i> Encourage students to think explicitly about global versus local challenges of the solution they came up with, in addition to what they improved. As students return to writing their answer, remind them to explicitly connect to the priorities they identified. Say, <i>Consider the priorities you heard in your interviews, and how they connect to both local and global impacts. As you revise your work, make sure to connect your grid solution ideas to specific priorities. These priorities will help you choose which local and global impacts to focus on.</i>	<i>Extending:</i> Challenge students by encouraging them to study the "Solution 2" tab in the Energy Grid Calculator. This tab shows all the various values and calculations that the calculator incorporates "under the hood". If students have considered the features at the bottom of the grid calculator, direct their attention here. Ask them to consider what the impact of factors like "underground power lines" or "pumped/gravity storage" might be. If a student wants to deviate from their group's solution, encourage them to do this on the Solution 2 or Solution 3 tab. Other group members may end up considering their ideas alongside what the group discussed together.
----------	---	--	---

Question 4. In your Engineering Design Tracker, you have considered new science ideas and applied these ideas to suggest possible changes to our electric grid.

- Describe 1 or more ideas from the Engineering Design Tracker that your group used to inform your design choices.
- Use evidence from the Engineering Design Tracker or related sources to explain why you made these specific design choices over other choices. What are the costs and benefits of this design choice? Why are these costs and benefits relevant to people and the planet?

This question could be made optional if time demands it. Students should ideally be using work from their Engineering Design Tracker that has already been completed. If this is not the case for a student or group, you may want to encourage them to use their time to prioritize other questions.

a) *Design choice: In the Engineering Design Tracker, we said that longer wires contribute to greater energy loss.*

b) *Explanation: We chose to build our solar panels and batteries inside the city, so the wires could be shorter. In the case of solar panels and lithium batteries, the local impact on health isn't negative, so it makes sense to put them in the city. Also, the Energy Source Statistics handout says "solar panels are often installed on the tops of buildings that are used for other purposes," so it makes sense to put them in the city where those buildings are already built.*

However, we made a different decision with our nuclear power plant, because nuclear plants can be harmful to humans if something goes wrong. This makes it much more risky to put a nuclear plant inside the city, so we thought it was worth the extra energy loss to put the nuclear plant 50 miles away. This also means that it costs a little bit more to build 50 miles of extra wire from the nuclear plant to the city, but the nuclear plant is really expensive already, so the extra wire doesn't add much.

Part 3: Communicate your community plan

Question 5. As a group, make a slide deck, poster, infographic, presentation, or video to communicate your plan. In your work, make sure to:

- Explain why our region's current grid solution has costs and risks associated with it, as well as benefits. (see Q2)
- Describe, in words and pictures or diagrams, the changes you made to our region's current grid solution, and justify your choices by describing the predicted impact those changes will have on your team's prioritized criteria. (see Q3)
- If you can, use 1 model from the unit to clearly demonstrate how your solution prioritizes reliability or other criteria. Use any model (or models) that you believe will be convincing to your audience. (see previous models)
- If you can, include relevant science ideas from your Engineering Design Tracker that help explain your choices. (see Q4)

Note about modeling in Question 5c:

This step is intended to encourage students to leverage work they have completed already throughout the unit by including relevant energy models in their presentation. As always, it is important for students to consider what they are "making models for", rather than just what they are "making models of". In this case, the models are "for" communicating to the audience of their presentation as to the rationale behind specific design choices. Students may find a number of systems relevant to their presentation, including but not limited to:

- Why does energy transfer through longer wire cause more energy loss to the surroundings?
- How does battery storage cause increased reliability when using wind and solar?
- How does using "dispatchable" sources help match supply to demand? Or: Why aren't most renewable sources "dispatchable"?

This serves two purposes:

- a. For students who mastered modeling throughout the unit, creating these models validates why modeling energy transfer is relevant to design questions.
- b. It provides an opportunity to support students with modeling energy transfer if they haven't mastered it yet.

As described above, this is a chance to support students who struggled deeply with energy modeling as a larger group. Using modeling work from the unit as a formative assessment, consider guiding these students to one particular scenario, depending on your assessment of their understanding. With this in mind, Question 5c iii above is likely the most straightforward to answer, as it is quite similar to the conversation about modeling that the class had early in the unit, in Lesson 3.

What to look and listen for in the moment:

- Students should list relevant components, such as: *gas plant or wind turbine, transport, house 1, house 2, house 3, surroundings*
- Arrows between these components should show energy transfer, labeled with values on the arrows, not the components. If students wish, they can use the diagrams on the back of *Energy Source Cards* to help decide values that represent efficiency for the source they chose.
- Supply should match demand, distributed among a few buildings equally or unequally. Each component should show “conservation of energy”—energy into the component equals total energy out.
- Students should draw a **second** (and perhaps even a third) model to show some change to the system, either decreased supply in the case of less access to wind or solar or a non-winterized plant, or increased demand, or both decreased supply and increased demand in the case of a winter crisis.
- The model should clearly show a contrast that either clearly shows buildings getting the same energy as before, **or** not getting enough energy, resulting in blackouts.

Foundational Understanding	Linked Understanding	Organized Understanding
Suggested Feedback	Lead a discussion with students about the impacts that this change could have, locally and globally. Identify specific sections from one common reading that students can use as an example. For example, say, <i>Many of you prioritized reducing carbon, but our state relies heavily on the (mining/fracking) mentioned in this reading about (coal/gas). What would be some of the local impacts of removing these sources from our grid?</i> Then, ask them to find a reading that's relevant to a source that they added more of. Say, <i>We just did one together as an example. Now use a reading that you choose to find some potential global and local impacts of adding more of this source to our grid. Remember, these impacts can be positive or negative, but they should emphasize the priorities that came up in your interview--try to think globally and locally.</i> Push students' logical reasoning, and ask them to go deeper, using their understanding of energy sources. Say, <i>What do you think would happen in our state if we experience very cold temperatures, like in Texas? Why do you think so? What might happen if carbon emissions from our grid continue to stay as high as they are now?</i> Brainstorm examples of sources and solution ideas that were most popular on the class consensus poster. For each, use readings to identify at least one positive and negative impact of each source. Say, <i>Notice, every source has trade-offs inherent to it. No source is entirely positive, so we have to prioritize.</i> After this discussion, encourage students to go back to their Energy Grid Calculator and check whether their solution maximizes the positive impact, according to their priorities. If they want to explore other solutions, encourage them to use the Solution 2 tab of the calculator to try out other ideas. Say, <i>You may have decided as a group on a solution that meets your priorities, but it's worth going back to see whether other solutions could meet those priorities even better.</i> If certain students are closer to mastering modeling energy transfer, but still need steering in the right direction, consider providing them with the materials that they used in class to develop and revise models. These include: Lesson 6 (for Question 5c i) : <i>Changing Fields</i> (focus on Situation C on Page 2), <i>Rubric for Modeling</i> Lesson 9 (for Question 5c ii) : <i>Modeling Reliability, Listening Group Roles Reference</i>	If students are looking for something much deeper, encourage them to investigate the "Background Data" tab of the Energy Grid Calculator. Almost every value that's being used is linked to a source, and students can investigate these as primary sources to see where they have questions or ideas on how to go deeper.

Lesson 11: Answer Key 2

Sand and Mirrors Assessment Key

Performance expectation being assessed: **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 motions of particles (objects) and energy associated with the relative positions of particles (objects). (SEP: 2.3, 4.6, 5.5; CCC: 5.2, 5.3; DCI: PS3.A.1, PS3.A.2, PS3.A.4, PS3.B.1, PS3.B.4, PS3.D.1, ETS1.B.1)

In addition to the SEP, CCC, and DCI associated with this PE, this assessment also addresses two additional SEP elements, one additional cross-cutting concept, and four additional DCI elements, described below:

3D Elements Addressed in This Assessment					
	1	2	4	5	6
2.3 Developing and Using Models Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	X		X		
5.5. Using Mathematics and Computational Thinking Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m ³ , acre-feet, etc.).				X	
4.6 Analyzing and Interpreting Data 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.			X		
PS3.A.1: 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. (HS-PS3-2)	X				
PS3.A.2: Definitions of Energy At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.	X				
PS3.A.4: These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). (HS-PS3-2)	X				
PS3.B.1: Conservation of Energy and Energy Transfer Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)			X		
PS3.B.4: Conservation of Energy and Energy Transfer The availability of energy limits what can occur in any system. (HS-PS3-1)				X	
PS3.D.1 Energy in Chemical Processes and Everyday Life Although energy cannot be destroyed, it can be converted to less useful forms--for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)			X		
ETS1.B.1: Developing Possible Solutions When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)					X
5.3 Energy and Matter: Flows, Cycles, and Conservation Energy cannot be created or destroyed--only moves between one place and another place, between objects and/or fields, or between systems.	X				
5.2 Energy and Matter: Flows, Cycles, and Conservation 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.	X	X	X		

Solar Sand Power Plants

Have you ever walked on a beach on a very hot day? You may have noticed that the sand is very good at storing energy, which we sense as heat.

Engineers are working on a way to harness the energy stored in sand to provide reliable and renewable electricity for communities.

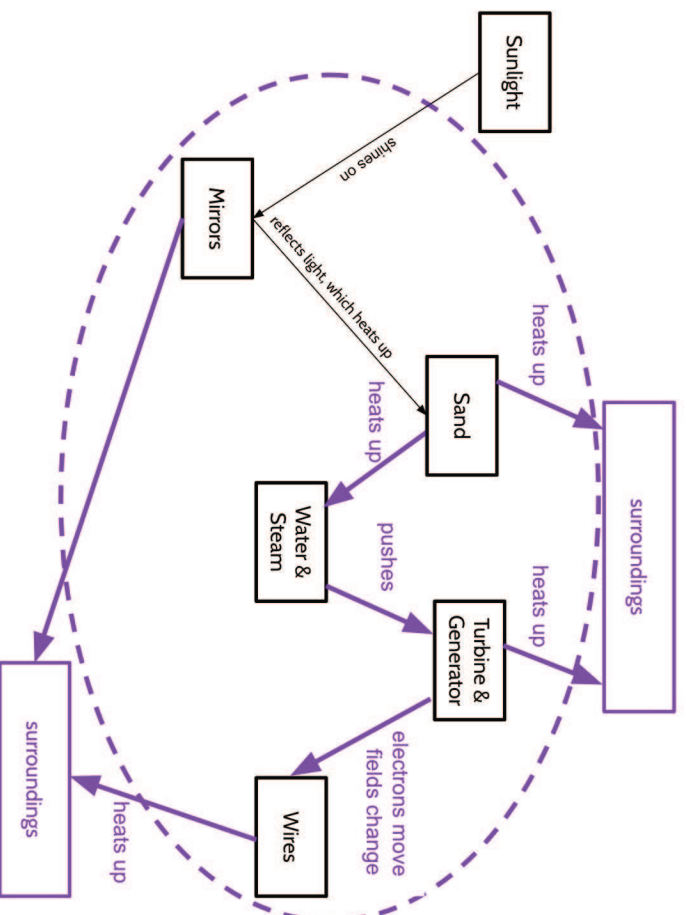


Only prototypes of sand power plants exist right now Amble, CC BY-SA 4.0

A solar sand power plant would use mirrors to reflect and concentrate sunlight onto a thin stream of sand as it drains from a higher basin into a lower one. This could heat the sand to as high as 1,000°C.

To transfer energy from the heated sand to an electrical turbine, the hot sand would be used to boil water and produce steam. The rising steam would turn a turbine, which produces electricity through a generator.

Students may show energy loss to the surroundings at this point, or they may come back and add energy loss in Question 3. If students have not completed Question 3, do not penalize them here for not including energy loss.



1. Complete the energy transfer diagram above to show how energy moves through the system described. Label the arrows in your diagram to show the mechanism for energy transfer between each system.

Only some of this sand is used to turn the turbines right away. The rest of the energy remains in the sand storage tank, and can be dispatched later.

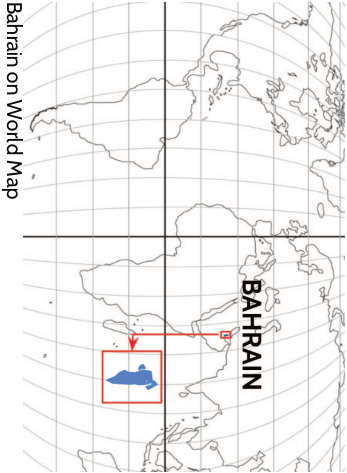
2. How might this technology help engineers provide the electricity that people need 24 hours a day?

The storage tank technology will help engineers provide electricity 24 hours a day because solar power isn't available at night. The storage tank means that some of the energy can be saved until nighttime when the sun isn't putting energy into the system.

Engineers at the University of Bahrain are considering the idea of building a solar sand facility to produce electricity for some of Bahrain's residents. In Bahrain, there is a lot of sand available in the surrounding desert.

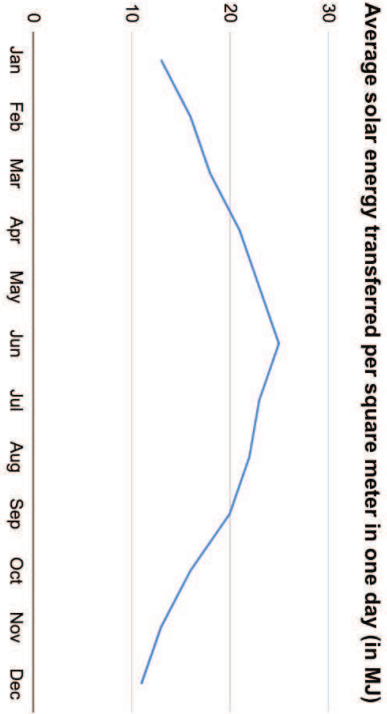
The strength and duration of sunlight in Bahrain changes seasonally.

The graph and data table below both show the average energy from sunlight in mega joules (MJ) that would reach each square meter (m^2) of reflective mirror at this location each day.



Bahrain on World Map

Month	Average solar energy transferred per square meter in one day (in MJ)
Jan	12.6
Feb	16.2
March	18
April	21.6
May	23.4
June	25.2
July	22.68
Aug	21.6
Sep	19.8
Oct	16.2
Nov	12.6
Dec	10.8



Engineers measured the amount of solar energy (energy from sunlight) reaching the solar sand system and the total energy available for communities at the end. They found that the total energy available for communities (output) was 20% of the amount of solar energy entering the system (input).

3. Annotate the energy transfer model above to account for the 80% of energy that does not get to communities. Label any new arrows to show the mechanisms for energy transfer out of the system.

See the diagram above.

4. If the efficiency of the sand and mirrors system is 20%, calculate the energy per day (in MJ) that would actually be available to be transferred into communities in Bahrain per 1 square meter (m²) of mirror.

$$10.8 \text{ MJ} * 0.8 = 8.64 \text{ MJ}$$

$$10.8 \text{ MJ} - 8.64 \text{ MJ} = 2.16 \text{ MJ}$$

OR

$$10.8 \text{ MJ} * 0.2 = 2.16 \text{ MJ}$$

5. The average daily total electrical energy demand in one community in Bahrain is 151 MJ per person. Use this information to determine whether 10,000 square meters (m²) of mirrors would be sufficient to reliably provide electricity to the community of 2,000 people.

$$(2.16 \text{ MJ/m}^2 * 10,000 \text{ m}^2) / 2,000 \text{ people} = 10.8 \text{ MJ/person}$$

OR

$$(2.16 \text{ MJ} * 10,000) / 2,000 \text{ people} = 10.8 \text{ MJ/person}$$

This is not sufficient to provide enough electricity.

6. What other factors should the community in Bahrain consider that might affect whether or not they choose to go with this system for electricity production?

- They may want to consider the fact that they have a lot of sand.
- They may want to consider that sunlight is renewable.
- They may want to consider the cost.
- They may want to consider whether there is enough room to build that many mirrors.

	Foundational Understanding	Linked Understanding	Organized Understanding
Indicator	Students struggle with questions throughout the assessment (modeling energy and calculations).	Most students are modeling energy transfer , but might struggle to include energy loss or setting up the calculations.	Most students in the class are successfully modeling energy transfer and energy loss , and setting up the calculations, even if they are making mistakes solving them.
Suggested Feedback	Work through some of the answers together as a class. Then give students the opportunity to retake the assessment.	Work through some of the answers together as a class. Then give students the opportunity to research and explain a different energy production with storage solution, such as hydropower with pumping or solar ponds.	Ask students to research and explain a different energy production with storage solution, such as hydropower with pumping or solar ponds.