Exploring grid resilience as an approach to evaluating energy sources and addressing climate impacts

Overview

In this interactive lesson, students evaluate the energy sources used to generate electricity in their state for their capacity to promote grid resilience in response to extreme weather events and rising seas. After considering the role of electricity in their lives and mapping their state's energy landscape, students explore how extreme weather events such as hurricanes and sea level rise impact the electrical grid and identify energy sources, technologies and innovations that promote grid resilience. This lesson incorporates content and readings from the *Fourth National Climate Assessment (Chapter 4: Energy Supply, Delivery, and Demand)* and can be supplemented with news articles about power outages during hurricanes and wildfires, etc. This lesson can be used to introduce students to one solution to promote grid resilience: distributed energy resources such as microgrids (see *Culminating Activities*).

> *"The Nation's energy system is already affected by extreme weather events, and due to climate change, it is projected to be increasingly threatened by more frequent and longer-lasting power outages affecting critical energy infrastructure and creating fuel availability and demand imbalances."*
> Fourth National Climate Assessment (2018)

Topics covered

Climate change
Distributed energy sources
Electric grid
- Electrical generation (from conventional and renewable energy sources)
- Transmission
- Distribution
- End-users (residential, commercial, industrial)

Energy storage
Extreme weather events (extreme heat, flooding, drought, etc)
Resilience
Sea level rise

Learning Objectives

Upon completion of this lesson, students will be able to:
- Describe the basic components of the electrical grid
- Describe the energy sources used to generate electricity in their state
- Define grid resilience
- List specific climate impacts to the electrical grid
- Describe how the grid is vulnerable to climate impacts
- Evaluate the resilience of different energy sources to various climate impacts
- Describe the features of a resilient electrical grid with emphasis on their state and region
- Describe solutions that promote a more resilient grid

Curriculum Alignment

North Carolina Essential Standards for 8th Grade Science

- 8.P.2 Explain the environmental implications associated with the various methods of obtaining, managing, and using energy resources.
- 8.E.1 Understand the hydrosphere and the impact of humans on local systems and the effects of the hydrosphere on humans.

North Carolina Essential Standards for Earth and Environmental Science

- EEn.2.2: Understand how human influences impact the lithosphere.
- EEn.2.4.2: Evaluate human influences on water quality in North Carolina's river basins, wetlands and tidal environments.
- EEn.2.5.5: Explain how human activities affect air quality.
- EEn.2.6.4 Attribute changes in Earth systems to global climate change (temperature change, changes in pH of ocean, sea level changes, etc.).
- EEn.2.7.3: Explain how human activities impact the biosphere.
- EEn.2.8.1: Evaluate alternative energy technologies for use in North Carolina.

Advanced Placement Environmental Science

Science Practice 1: Explain environmental concepts, processes, and models presented in written format.
Science Practice 2: Analyze visual representations of environmental concepts and processes.
Science Practice 7: Propose and justify solutions to environmental problems.

ENDURING UNDERSTANDING ENG-3
Humans use energy from a variety of sources, resulting in positive and negative consequences.

ENDURING UNDERSTANDING STB-2
Human activities have physical, chemical, and biological consequences for the atmosphere.

ENDURING UNDERSTANDING STB-3
Human activities, including the use of resources, have physical, chemical, and biological consequences for ecosystems.

Next Generation Science Standards

Disciplinary Core Ideas	Science & Engineering Practices	Cross Cutting Concepts
• ESS2.D: Weather and Climate • ESS3.A: Natural Resources • ESS3.B: Natural Hazards • ESS3.C: Human Impacts on Earth Systems • ESS3.D: Global Climate Change • ETS1.B: Developing Possible Solutions	• Asking questions and defining problems • Constructing explanations and designing solutions • Obtaining, evaluating and communicating information	• Cause and effect • Systems and system models • Stability and change
Relevant Performance Expectation	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.	

Energy Literacy Framework

Essential Principle 4: Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.

Climate Literacy Framework

Essential Principle 7: Climate change will have consequences for the Earth system and human lives.

Instructional Materials

- Internet
- Companion PowerPoint
- Graphic organizer, *Grid Resilience (Parts I and II)*, provided, one per student
    - MS Word version, provided at end of lesson along with answer key
    - Google Document (you'll need to make a copy for use in your classroom)
- [Optional] Provide access to excerpts from the *Fourth National Climate Assessment (Chapter 4: Energy Supply, Delivery, and Demand)* such as page 175-176, which includes the Executive Summary and summarizes the three key messages in the chapter, and/or pages 186-189 which summarizes Key Message 3: Improving Energy System Resilience.
- [Optional] Provide access to news articles from recent climate-related events that resulted in power outages.
- [Optional] Small whiteboards with markers for group work and/or student access to technology tool (e.g., Kahoot, Padlet, Poll Everywhere) that lets students share written responses anonymously. Opportunities to use this approach with students will be denoted with this symbol:

Lesson At-a-Glance

Activity	Instructional Time Needed
Explore the role of electricity in our lives	10-15 minutes
Introduce the electric grid	10-15 minutes
Introduce grid resilience	15-20 minutes
Map the energy landscape	20-30 minutes
Identify vulnerabilities	20-30 minutes, could be extended
Identify solutions	20-30 minutes, could be extended
Evaluate resilient options	25-30 minutes

Teacher Preparation

This activity is intended to build upon students' knowledge of 1) the energy sources (renewable and non-renewable) used to generate electricity; and 2) the specific impacts arising as a result of climate change by addressing weather-related events (such as extreme heat) and sea level rise.

- Review the procedure below and the Companion PowerPoint and add any additional figures and/or slides if desired. For instance, you may choose to incorporate images and/or news headlines from a recent climate-related event that resulted in a local power outage.
    - **If you teach in a state other than North Carolina**, customize slide 8 to show students the energy sources that power your state (NC is default state). To find this information for your state visit: https://www.eia.gov/beta/states/overview
- Familiarize yourself with EIA's U.S. Energy Mapping System at https://www.eia.gov/state/maps.php
    - Zoom in on your state and then click on the "Layers/Legends" tab in the top left corner of the map. From here, you can select the map layer(s) of interest. It can be helpful to select "Remove all" and then proceed by selecting the layer(s) of interest. Once a map has been created, select "Print" to obtain a pdf version of the map for insertion into a document or slide presentation. Students can use the print screen feature to capture a screen shot of their map.

- Make the graphic organizer available to students online or, if teaching in person, print one copy per student.
- Decide if you want to provide students with hard copies or hyperlinks to the optional readings suggested in *Instructional Materials*.
- Determine what the final student product will be and let your students know upfront what they are working towards. You may consider asking students to prepare proposals for making the grid more resilient to present to the class or to local officials, or to design a resilient grid for a community recovering from a climate-related disaster (See *Culminating Activities*).

Procedure

1. **Explore the role of electricity in our lives:** Prompt students to consider the ways they rely on electricity in their life. Students can brainstorm in small groups and record their responses on a whiteboard before sharing aloud, or the whole class can brainstorm, in which case you could use a digital technology tool to collect anonymous student responses; time permitting, this prompt could be offered as a journaling assignment and/or as a visual art activity where students make individual or collaborative collages.

2. Ask the class to reflect on a recent event that led to a widespread power outage in their community. Ask "What do we lose when we lose power?" (slide 2). Students can refer to their responses to the activity above to answer this question. This prompt should lead students to recognize the many ways they rely on electricity in their lives and recognize that access to electricity provides necessary services to homes, schools and communities, etc.

3. Next, project slide 3 and ask students what they think the diagram is trying to convey: that **<u>many sectors of our society are dependent upon electricity.</u>** [Optional] To extend this conversation, either show or have students determine the percent of electricity used by the transportation, industrial, residential and commercial sectors (See *US Energy Consumption by Source and Sector, 2019* at: https://www.eia.gov/energyexplained/us-energy-facts/)

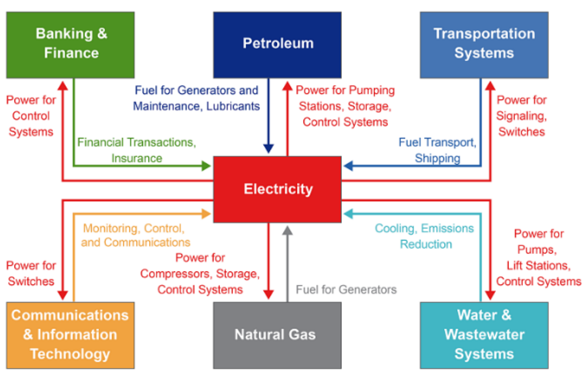

Figure 1. Examples of Critical Infrastructure Interdependencies. *Source: National Climate Assessment, 2018* (Chapter 4).

4. **Introduce the electric grid:** Project a schematic diagram of an electric grid (slide 4) to introduce (or review) the following **terminology:**
   - generation (from conventional and renewable energy sources)
   - transmission
   - substation
   - distribution
   - end-users (residential, commercial, industrial)

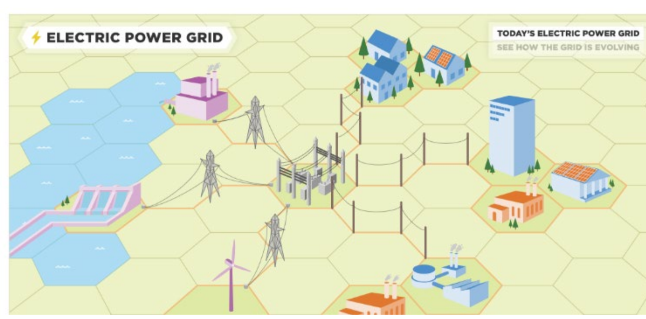

Figure 2. Schematic of today's power grid (Note: an interactive schematic is available). *Source: US EPA.* https://www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment

5. Project slide 5 and ask "Why do we lose power?" In general, responses will fall into the following categories: 1) disruption to power generation, and 2) disruption to transmission or distribution of power, so be sure to point out this distinction before proceeding.

6. **Introduce resilience:** Ask students to reflect on the question(s) "What is grid resilience?" (slide 6) and/or "What are the *features* of a resilient electrical grid?"(slide 7); alternatively, you may choose to use this prompt as a pre-assessment. Compile student responses and collectively try to come up with a definition of grid resilience/features of a resilient grid. Your students may enjoy finding and comparing other definitions of grid resilience; two definitions are offered below.

> The National Academy of Sciences (2018):
> *Resilience is not the same as reliability. While minimizing the likelihood of large-area, long-duration outages is important,* ***a resilient system*** *is one that acknowledges that such outages can occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from the experience to improve performance in the future.*

> Natural Resources Defense Council (2018):
> ***"Resilience"*** *typically refers to providing* ***reliable power*** *service during normal and challenging conditions,* ***recovering quickly*** *from extreme weather and other damaging events, and* ***minimizing harmful impacts*** *to public health and safety.*

7. Ask students if they think their state's power grid is resilient - ask them to elaborate on their responses based on what they know and what their lived experience tells them about this system. Frequent power outages at home or school would be an indication that the grid is "not resilient."

8. As weather-related events increase as a result of climate change, the need to minimize disruptions to the power grid is essential. Tell students that the rest of this lesson will invite them to investigate their state's current energy portfolio and to consider how the electric grid can become more resilient to impacts brought about by a changing climate.

9. Project slide 8 to show students which energy sources power their state (NC is default state).

10. Divide students into pairs or small groups and assign each group a specific energy source (e.g., solar) from their state's portfolio.

11. **Map your state's energy landscape:** Ask students to visit https://www.eia.gov/state/maps.php to investigate the prevalence and distribution of their assigned energy source across their state and to also consider the production (e.g., coal mining) and transport (e.g., train) of relevant fuel sources as well as the transmission and distribution of electricity via power lines. Students should use the mapping tool to make their own map and transfer their map into their graphic organizer (Part 1.1) and/or to a PowerPoint or Google slide. [Optional] Ask students to briefly present their map to the class so that the whole class can get a sense of their state's energy landscape. You could emphasize relevant trends such as the increased use of natural gas for electricity and/or the increased use of renewables as evidenced by the growth in utility scale solar farms for instance; these changes have helped to diversify a state's energy portfolio and this contributes to a more resilient grid.

> *Note: If time is limited, you could present students with a map of your state's power plants highlighted and proceed to next step. A default map for NC has been provided (slide 9).*

12. Students should complete Part 1.2 to get them thinking about production and distribution of their assigned energy source, including fuel source (if applicable), electricity generation, transmission, distribution as well as end-user demand for electricity.

13. Ask students to give examples of <u>specific weather/climate-related events</u> (e.g., extreme precipitation or sea level rise) that have or could impact the electric grid <u>in their state</u> (slide 10). **Compile this list on the board and decide which events the class will address and record these in the first column of Part 1.3.** You may want to show NOAA's Billion-Dollar Weather and Climate Disasters map (see *Resources*) to remind students of the major climate events that occurred in the US in the previous year.

Note: This prompt is highly recommended as it will keep students focused on climate variables as opposed to all things that might disrupt the grid such as earthquakes, terrorism, squirrels, etc.

14. **Identify vulnerabilities**: <u>The schematic in Part 1.2 can be used to consider the vulnerabilities associated with this energy source in response to various climate impacts</u>. When identifying **vulnerabilities** consider elements of the system that could be damaged or disrupted and result in a power outage or lead to additional threats such as fire. <u>Be sure to remind students to include vulnerabilities that also arise when considering impacts to human health and natural resources as well</u>. For example, the 2019 California wildfires revealed how downed powerlines start wildfires during high wind events, especially when combined with drought conditions, and that wildfires contribute to poor air quality, displacement from homes, etc.

    Either in class or as a homework assignment, direct students to conduct independent research to determine how their assigned energy source <u>and associated infrastructure</u> is vulnerable to each climate event based on typical conditions in their state (slide 11). In the middle column of their graphic organizer they will list specific vulnerabilities that arise in response to the climate event (e.g., potential for downed power lines in response to high winds). Students should prepare to present their findings to the class. Alternatively, you may choose to ask students to summarize their analysis in writing. This activity should ultimately prepare students to discuss the overall vulnerability of their energy source and associated infrastructure to climate impacts and can be used to prompt a class discussion about the need to promote grid resilience through adoption of solutions that either already exist or that could be developed to reduce vulnerability.

    Note: If time is limited, you could project slides 12 and 13 to the class which ***summarizes some of the possible vulnerabilities that can arise from extreme weather and climate change from the National Climate Assessment*** *and is also shown in Figure 3 below.*

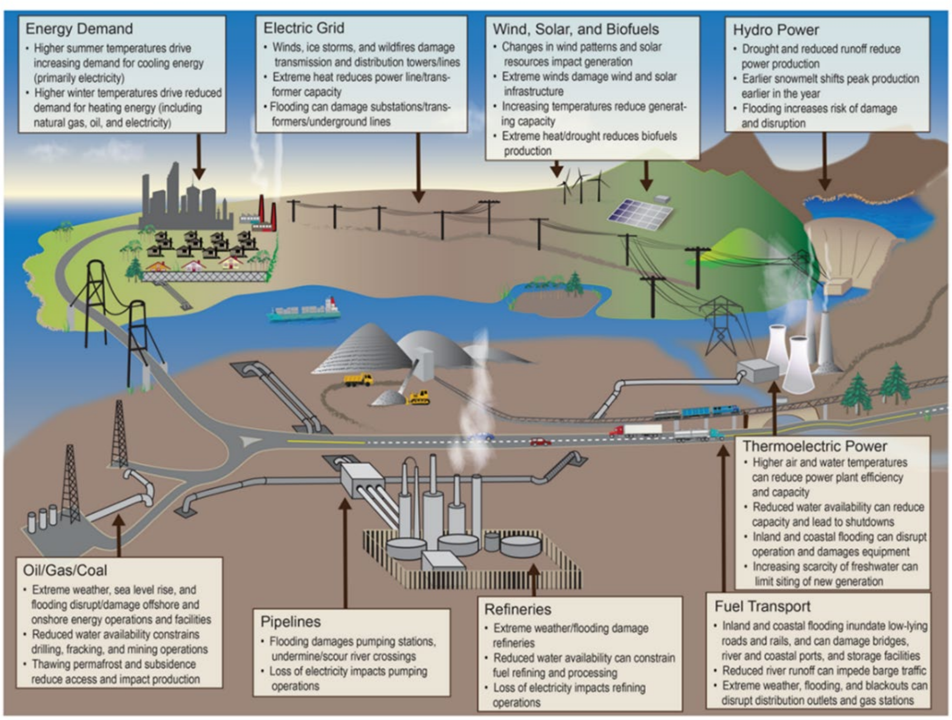

Figure 3. Extreme weather and climate change impacts to energy system. Source: *National Climate Assessment, 2018* (Chapter 4).

15. **Identify solutions:** Students will complete the right-hand column in Part 1.3 by listing solutions (technologies and behaviors) to address each vulnerability and ultimately make the grid more resilient (slides 14 and 15). The solutions should directly or indirectly address the energy needs of communities while also keeping in mind the problems (like more frequent and stronger hurricanes coupled with rising sea levels) that the state will experience in the future. Students can conduct research and look for news articles to learn about technologies and actions that are being implemented in communities across the world. They may also come up with some new ideas that don't even exist yet!

16. Remind students how you would like them to share their findings (vulnerabilities and solutions) with the class; students could prepare an informal 2-3 minute summary or they could prepare short slide presentations, design a poster, or a write a summary. To bring a civic engagement component to this activity, students could present their findings to local government officials and/or representatives of the electric sector.

17. While students are presenting on their assigned energy sources and summarizing the vulnerabilities and solutions they identified, ask the rest of the class to reflect on what they are learning and complete Part II of the graphic organizer. Each group should remind the class about the extent (% generation) to which their assigned energy source is used to generate electricity in your state and complete Part 2.1. Completion of Part II will guide students in thinking about which energy sources are most vulnerable and most resilient depending on the climate event. ***An answer key has been provided.***

18. [Optional] Invite students to read an excerpt from the *Fourth National Climate Assessment (Chapter 4: Energy Supply, Delivery, and Demand)* such as page 175-176, which includes the Executive Summary and summarizes the three key messages in the chapter, and / or pages 186-189 which summarizes Key Message 3: Improving Energy System Resilience.

19. Project summary of energy resilience solutions (slide 16) so students can see that some of their solutions are also on this list and to show them that they may have come up with other, and potentially new ideas.

Figure 4. Energy Sector Resilience Solutions. Source: *National Climate Assessment*, 2018. (Chapter 4)

20. **Evaluate resilient options:** Conclude this activity with an in-class discussion. You may consider asking any, or all, of the following questions depending on your instructional goals:
    - In general, which energy sources are associated with resilience to hurricanes? Wildfires? Sea level rise? Extreme heat?
    - What technologies and innovations promote grid resilience?
    - What can our community do to minimize power outages during the next hurricane (or wildfire, etc)?
    - How can your household become more resilient in the face of a power outage? Our school?

21. Conclude by revisiting the EPA schematic (slide 17), this time showing students the graphic titled "See how the grid is evolving" which now includes more renewable energy, as well as other features that promote resilience, such as energy storage and distributed energy resources. A "distributed" energy source is in contrast to a centralized energy source such as a large power plant that distributes electricity to the grid. According to the US Department of Energy, a **distributed energy resource (DER)** is a source of electric power (often renewable energy sources but can also include generators and energy storage technologies) located near the point of use as the EPA schematic depicts. It is important to note that both renewable energy resources, energy storage and DER introduce new challenges to the grid.
22. Ask students if they are seeing any evidence of the grid evolving in their community or across their state and/or have them conduct research to find examples in their state.

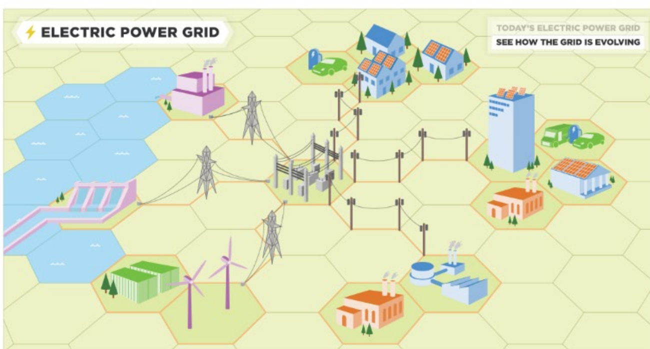

Figure 6. Schematic of the evolving power grid.
Source: US EPA.
https://www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment

Culminating Activities

Learn about distributed energy sources and microgrids

Distributed energy sources generate electricity at or near where it will be used by consumers. Examples of distributed energy sources include solar panels, combined heat and power, backup generators, energy storage, etc. A **microgrid** is a localized group of one or more distributed energy sources and loads (such as battery storage) that is typically connected to the main grid but has the capability to disconnect and operate in isolation from the main grid. Microgrids can be used to provide power to one or more buildings, or even a campus or community. There are also mobile microgrids that can be deployed during disasters.

About Microgrids: *How Microgrids Work* from the Department of Energy
https://www.energy.gov/articles/how-microgrids-work
Educational video: *Microgrids* (2:47 min) from Wisconsin Energy Institute
https://youtu.be/qwVggeO_GTY
Hands-on activity: *Modeling Power Grids with Snap Circuits (Lesson Plan)* from Wisconsin Energy Institute
https://energy.wisc.edu/education/for-educators/educational-materials/modeling-power-grids-snap-circuits

Design a resilient grid

Invite students to apply what they have learned and design an updated and more resilient electrical grid for a real or fictitious town/city, state, or island.

Interact with experts

- Invite someone from the electricity sector to discuss how they are working to strengthen or "harden" the power grid.
- Invite a local government representative to discuss the adoption or potential adoption of technologies to make your community more energy resilient.
- Tour a local microgrid facility or learn about a local microgrid.
    - In NC, Duke Energy operates a few microgrids that students can learn about:
        - Mc Alpine (Solar and battery storage facility to provide backup power to fire station)
        - Mt Sterling (Solar and battery storage facility in Great Smoky Mountains National Park)
        - Hot Springs (Solar and battery storage facility to provide backup power to Hot Springs, NC)
        - Also see: https://www.duke-energy.com/renewable-energy/microgrid
    - Butler Farms in Lillington, NC is a hog farm with a microgrid. To learn more visit: https://powersecure.com/distributed-infrastructure/microgrid/#

Differentiation

Students with special needs

- Place students in mixed ability partners for activity completion.

AIG

- Students can work individually.
- Ask students to summarize their findings in writing and support their work with independent research.

Resources

National Climate Assessment, 2018. Chapter 4
https://nca2018.globalchange.gov/chapter/4/

Electricity explained: How electricity is delivered to consumers
https://www.eia.gov/energyexplained/electricity/delivery-to-consumers.php

About the U.S. Electricity System and its Impact on the Environment
https://www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment

U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather (2013 Report)
https://www.energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf
Interactive US Map (2013): https://www.energy.gov/articles/climate-change-effects-our-energy

National Academies of Sciences, Engineering, and Medicine. 2017. *Enhancing the Resilience of the Nation's Electricity System.* Washington, DC: The National Academies Press. https://doi.org/10.17226/24836.

NOAA's Billion-Dollar Weather and Climate Disasters
https://www.ncdc.noaa.gov/billions/

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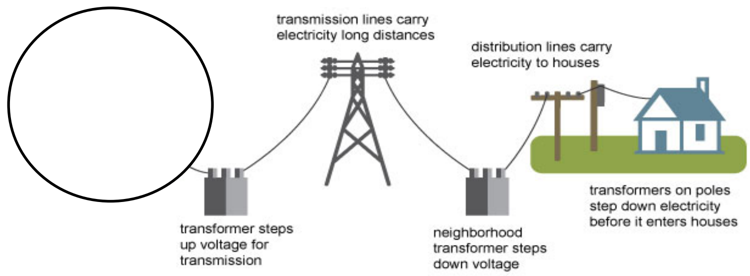
Grid Resilience | Part I. Exploring an energy source: write in assigned energy source **Name:**

1.1 Insert map showing prevalence and distribution of assigned energy source across the state.

1.2 Finish the schematic below by drawing your assigned power plant (e.g. a solar farm) in the circle and, depending on your energy source, include production and transmission of any raw materials to the left of the circle.



1.3 Identify how your assigned energy source and associated infrastructure is vulnerable to each climate event and describe possible solutions to address each vulnerability.

Climate Event	Identify Vulnerabilities	Identify Solutions (existing and future)

Grid Resilience | Part II. Evaluation of Energy Sources

2.1 As you learn from other groups, shade the circle to indicate the % of each energy source used to generate electricity in your state:

2.2 For each climate event below, record what you think are the most vulnerable and most resilient energy sources based on what you learn from other groups.

Climate event	Most vulnerable energy source(s)	Most resilient energy source(s)
Cold winter temps & ice storms		
Drought / reduced water availability		
Extreme heat		
Flooding / extreme rainfall		
High winds/ storms and hurricanes		
Sea level rise		

Grid Resilience | Part I. Evaluation of Energy Sources **Answer Key** **Note: This is not a comprehensive answer key**; students should conduct research to complete this table for their assigned source and, given the timeliness of the topic of grid resilience, they will encounter research taking place to better understand vulnerabilities and to develop and test solutions. **To constrain their research, students can focus on the climate in their region (e.g. a winter climate in NC is very different from that of Alaska, so vulnerabilities and solutions may look different) and on their state's electricity generation portfolio.**		
1.3 Identify how your assigned energy source and associated infrastructure is vulnerable to each climate event and describe possible solutions to address each vulnerability.		
Climate Event	**Identify Vulnerabilities**	**Identify Solutions (existing and future)**
Cold winter temps & ice storms	Grid infrastructure (e.g. substations and power lines) -*Downed transmission/distribution towers and lines mean electricity can't get to homes and businesses* *-Equipment may operate slower than normal under extreme cold temperatures (since range of extreme operating conditions is considered in planning, procurement, and installation of equipment, the prevalence of this impact may depend on extent to which conditions are outside of "normal")*	*-Bury power lines (but this is costly)* *-Manage vegetation around powerlines* *-Back-up generators and microgrids with energy storage technologies can provide power when main grid fails* *- Advanced communications and smart meter technologies provide grid operators the ability to more quickly locate outages and manage repair efforts so outages may not last as long*
	Thermal power plants (coal, oil, natural gas, nuclear and biopower) *-Disruptions to fuel supply (roads, rail, pipelines) (e.g., downed trees block railroad; coal stockpiles can freeze)* *-Power lines that facility uses to send electricity to the grid could become impaired causing the plant to have to reduce its generation or to shut down*	*-Consider climate impacts and address vulnerabilities in the resource planning to ensure adequate fuel supply for extended period of time* *- Power plants have back-up fuel source(s) to respond to decreased supply of primary fuel source* *- Other power plants can increase generation to make up for plant that is offline or operating at reduced capacity*
	Renewables (hydro, solar photovoltaic, wind) *Ice and snow could impede electricity generation as well as access to generation sites for maintenance* *[solar] Ice and snow can accumulate and block electricity generation* *[wind] Ice can accumulate on blades and detach as it melts to form "ice throws"* *[hydro] Ice could impair operations; intake gates and spillway gates could freeze*	*[solar] panels are typically installed at an angle which helps to prevent accumulation of ice/snow; self-cleaning surfaces (e.g., hydrophobic coatings) repel rain and snow* *[wind] de-icing strategies might include: painting blades black; heating the surface of blades; coating or surface design to repel ice*
Drought/ reduced water availability (e.g. due to decreased snowpack, shift in timing of snowmelt)	Grid Infrastructure (e.g. substations and power lines) - *Drought, especially when combined with high winds, conditions can increase risk of wildfires which can damage transmission/distribution towers and lines* *- Drought conditions in combination with high summer temperatures (which increases demand for electricity) stresses the electric grid and could result in power outages (blackouts and brownouts)*	*-Bury power lines* *-Manage vegetation around powerlines* *-Implement consumer initiatives to reduce demand during drought events* *-During dry, windy conditions, take power lines in high fire risk areas offline to prevent wildfire and damage to infrastructure (this is what PG&E did in California in 2019). If transmission line is connected to a power generating facility, that means taking the power plant offline as well.*
	Thermal power plants (coal, oil, natural gas, nuclear and biopower) *--Drought conditions can increase risk of wildfires which can damage power plants*	*-Utilize solar and wind energy for electricity generation to the extent possible* *-Adding or improving cooling or ventilation equipment to improve system performance and reduce water withdrawals during drought*

	-Reduced water supply constrains oil and gas drilling, fracking, mining operations that need water for cooling *-Reduced water supply can reduce power plant capacity and lead to shut down since these plants rely on water for cooling* *-In case of severe drought and low water levels, water intake structures may be exposed leading to shutdown* *-Plants that discharge heated water (thermal pollution) into lakes and rivers can impair aquatic ecosystem; this effect could be more pronounced when water levels are low because of drought*	*conditions; using nontraditional water sources, including brackish or municipal wastewater (NCA, 2018)* *- According to the Energy Information Administration, over half of the cooling systems at U.S. electric power plants **reuse water** via "closed-cycle, hybrid and other systems."* *- According to the Energy Information Administration, there are often **regulatory limits** on the temperature of the water that can be discharged*
	Renewables (hydro, solar photovoltaic, wind) *[solar] Dust from drought conditions can coat solar photovoltaic panels and decrease power output (this has been documented in India for instance)* *[hydro] Reduced water supply can reduce power plant capacity and lead to shut down* *[biofuels] Drought could impact crop production, availability of wood products for biopower plants*	*[solar] self-cleaning surfaces to keep panels clean* *[hydro] store more water in reservoir in anticipation of drought; switch to solar and wind energy sources to conserve water* *[biofuels] utilize drought-tolerant biofuel sources*
Extreme heat	Grid Infrastructure (e.g. substations and power lines) *- Extreme heat reduces capacity of power lines to move electricity and can lead to sagging of lines and possible overheating of other equipment* *- Drought conditions in combination with high summer temperatures (which increases demand for electricity) stresses the electric grid and could result in power outages (blackouts and brownouts)* *- Electrical workers can be impacted by extreme heat*	*-Bury power lines* *-Implement consumer initiatives such as energy efficiency programs, demand response programs to reduce demand during extreme heat events* *-Shift time of day maintenance occurs to protect line workers*
	Thermal power plants (coal, oil, natural gas, nuclear and biopower) *-Higher air and water temperatures can reduce power plant efficiency* *-If water needed for cooling is too warm, the plant may have to shut down operations* *-Plants that discharge heated water (thermal pollution) into lakes and rivers can impair aquatic ecosystems; this effect could be more pronounced when waters are warmer than usual and/or low due to accompanying drought conditions* *-Increased demand for air conditioning will increase emissions of air pollutants (e.g., nitrogen oxide and sulfur dioxide) from fossil fuel plants which threatens air quality especially on hot, stagnant days*	*-Reduce emissions from coal and gas plants during extreme heat events to minimize impacts to air quality* *-Add or improve cooling or ventilation equipment to improve system performance during extreme heat conditions (NCA, 2018)* *- According to the Energy Information Administration, there are often **regulatory limits** on the temperature of the water that can be discharged*
	Renewables *[solar] As temperature goes up, electricity generation decreases but the extent to which this*	*-Shift time of day maintenance occurs to protect workers* *[solar] In "over-sizing", more solar panels are installed than needed, so the overall generating*

	occurs is influenced by other variable such as humidity *[biofuels] Higher temperatures could impact crop production, availability of wood products for biopower plants*	*capacity can be met even if the power from individual solar panels is reduced.* *-Install panels to enable air flow underneath; utilize shade underneath panels to protect other equipment; students can conduct research to learn more about which panels perform best in hot conditions and to see if other cooling strategies are being tested.*
Flooding/ extreme rainfall	Grid Infrastructure (e.g. substations and power lines) -*Downed power lines due to fallen trees, failed powerline foundations* *-Damaged substations, transformers, underground lines, pipelines*	*-Elevate substations and back-up generators* *-Manage vegetation around powerlines* *-Relocate or avoid placing infrastructure in frequently flooded areas* *- Solutions in response to Hurricane Sandy included: installing submersible equipment and floodwalls, elevating equipment, redesigning underground electrical networks, and installing smart switches to isolate and clear trouble on power lines (NCA, 2018)*
	Thermal power plants (coal, oil, natural gas, nuclear and biopower) *-- Low-lying facilities and infrastructure, including roads and railroads for fuel transport, are at increased risk of flooding as result of heavy precipitation* *- Inland facilities that rely on ports, coastal storage facilities, etc., could be impacted by disruptions*	*Answers will vary as flood protection strategies differ depending on land use, geology, type of power plant, etc; have students conduct research to learn what vulnerable facilities in their state are doing*
	Renewables *- Low-lying facilities and infrastructure, including roads at solar and wind farms are at increased risk of flooding as result of heavy precipitation this could damage equipment and prevent timely maintenance* *[hydro] flooding can damage equipment and lead to downstream impacts*	*Answers will vary as flood protection strategies differ depending on land use, geology, type of power plant, etc.; have students conduct research to learn how renewable energy facilities in their state are being protected from flooding* *[hydro] open flood gates to safely manage flood waters*
High winds / storms and hurricanes	Grid Infrastructure (e.g. substations and power lines) -*Downed transmission/distribution towers and lines; downed trees can also block roads necessary for maintenance*	*- Bury power lines* *- Manage vegetation around powerlines* *- Advanced communications and smart meter technologies provide grid operators the ability to more quickly locate outages and manage repair efforts*
	Thermal power plants (coal, oil, natural gas, nuclear and biopower) *-Power plants, cooling towers, fuel storage facilities can be damaged during high wind events and may be taken offline in anticipation of high winds* *- Low-lying facilities and infrastructure, including roads and railroads for fuel transport, are at increased risk of flooding as result of **storm surge** (where seawater comes inland due to high winds)*	*Typically, it is power lines/poles/towers that are most vulnerable during storms and high wind events and not power generation facilities themselves but students can research what power generation facilities, especially along coastlines are doing to prepare for more frequent and more intense hurricanes (and storm surge)*

	Renewables *- Low-lying facilities and infrastructure, including roads, are at increased risk of damage from storm surge- this could damage equipment and prevent timely maintenance* *-[wind] Changes in wind patterns and wind speed can impact generation; could go offline during storms, reducing generation capacity* *-[solar] panels can be damaged by flying debris, fallen trees, etc.; could go offline down during storms, reducing generation capacity*	*Students can investigate the research taking place to inform the design of offshore and onshore turbines and their foundations to withstand hurricane force winds* *[wind] turbines placed into storm mode so that they don't catch the wind*
Sea level rise	Grid Infrastructure (e.g. substations and power lines) *Low-lying facilities and infrastructure at the coast are at increased risk of damage from rising sea levels*	*See solutions for flooding above; students can investigate how coastal communities are working to protect and strengthen the electric grid in response to sea level rise. For example, is sea level rise being considered when siting new electric production facilities? When retiring older facilities?*
	Thermal power plants (coal, oil, natural gas, nuclear and biopower) *- Low-lying facilities and infrastructure including roads, railroads, ports (for fuel transport) and storage facilities are at increased risk of damage from rising sea levels* *- Inland facilities that rely on ports, coastal storage facilities, etc., could be impacted by disruptions*	
	Renewables *- Low-lying facilities and infrastructure, including roads, are at increased risk of damage from rising sea levels* *- Sea level rise can also result in isolation of power generation facilities and substations, etc. making maintenance difficult and potentially impairing their function*	

2.2 For each climate event, record what you think are the most vulnerable and most resilient energy sources.

Answers will vary depending on the extent to which these conditions occur in your state as well your state's electricity portfolio; students can use news articles to learn how various energy sources fared during recent climate events.

Climate event	Most vulnerable energy source(s)	Most resilient energy source(s)
Cold winter temps & ice storms	*Typically, it is power lines/poles/towers that are most vulnerable during winter storms but vulnerable energy sources may include* ***those that have to be transported to power plants such as coal, gas and oil*** *as transportation could be disrupted*	***Energy sources that do not have to be regularly transported*** *to a power plant such as* ***solar and wind; also nuclear*** *which has fuel replaced every 18 to 24 months*
Drought	***Energy sources that rely on a water supply*** *for operation and cooling such as* ***hydropower, coal, natural gas, nuclear***	***Energy sources that don't rely on a water supply*** *such as* ***solar and wind and natural gas combined cycle technologies***
Extreme heat	***Thermoelectric power plants (coal, oil, gas, nuclear) that use freshwater for cooling*** *as water*	***Hydropower and natural gas plants*** *that can ramp up quickly in response to increased demand (for air conditioning), as well as* ***wind power and solar***

	temperatures may be too warm for efficient operations	***power*** *since they are not reliant on water for cooling*
Flooding/ extreme rainfall	*Flooding can impact both above and below ground structures and equipment as well as maintenance operations, so* ***most energy sources are going to be vulnerable to floods***	***Nuclear power*** *facilities are, by design, resilient to extreme weather events and* ***wind turbines*** *with their solid bases are also likely to withstand floods though transmission could be impacted if powerlines are impaired*
High winds/ hurricanes	*Typically, it is power lines/poles/towers that are most vulnerable during high wind events but vulnerable energy sources may include* ***those that have to be transported to power plants such as coal, gas and oil*** *as transportation could be disrupted*	***Wind turbines are optimized to catch the wind*** *and turbine design and behavior coupled with foundation technology can help them to withstand hurricane force winds* ***Nuclear power*** *facilities are, by design, resilient to extreme weather and high wind events* ***Renewable energy technologies*** *like solar and wind have been shown to be resilient to storms, coming online quickly after storms have passed; however, the ability to generate and deliver electricity is also determined by the grid infrastructure (e.g., powerlines)*
Sea level rise	*Sea level rise can impact both above and below ground structures and equipment, so* ***most energy sources are going to be vulnerable***	*Resilient energy sources are going to include those that are* ***located in areas not at risk of sea level rise and/or designed (e.g. elevated) and built with sea level rise taken into account****; also includes inland facilities that don't rely on at risk facilities at the coast*