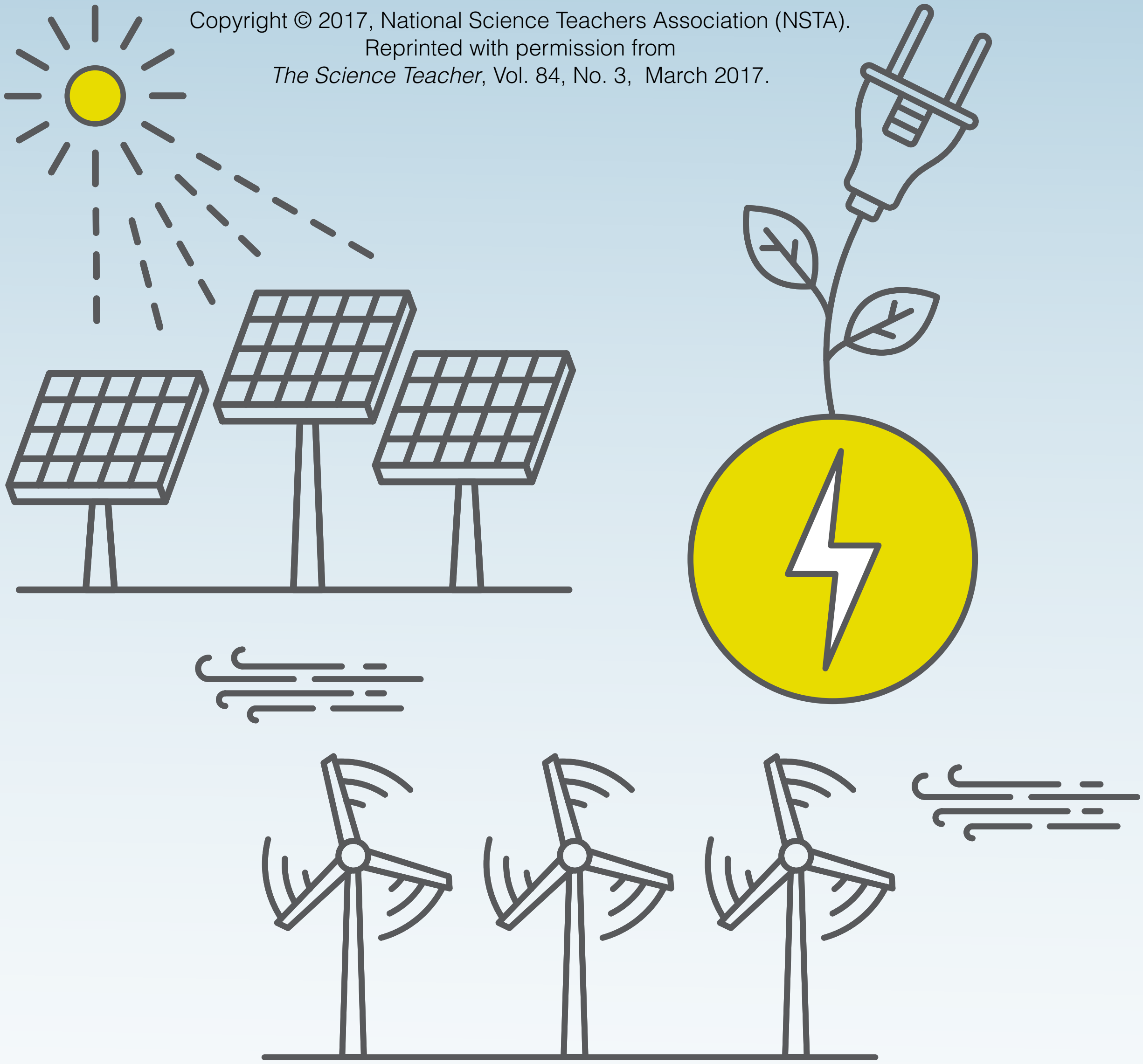


The FUTURE of ENERGY

Having students compare the effects of different energy sources on the environment

Amy Pallant, Sarah Pryputniewicz, and Hee-Sun Lee

The energy sources we use to generate electricity are changing due to concerns about pollution and climate change, the rise of affordable renewable energy, and the current availability of low-cost natural gas. Because the infrastructure to supply energy requires an enormous investment, our decisions today will have long-term effects. When considering our energy future, we must consider:

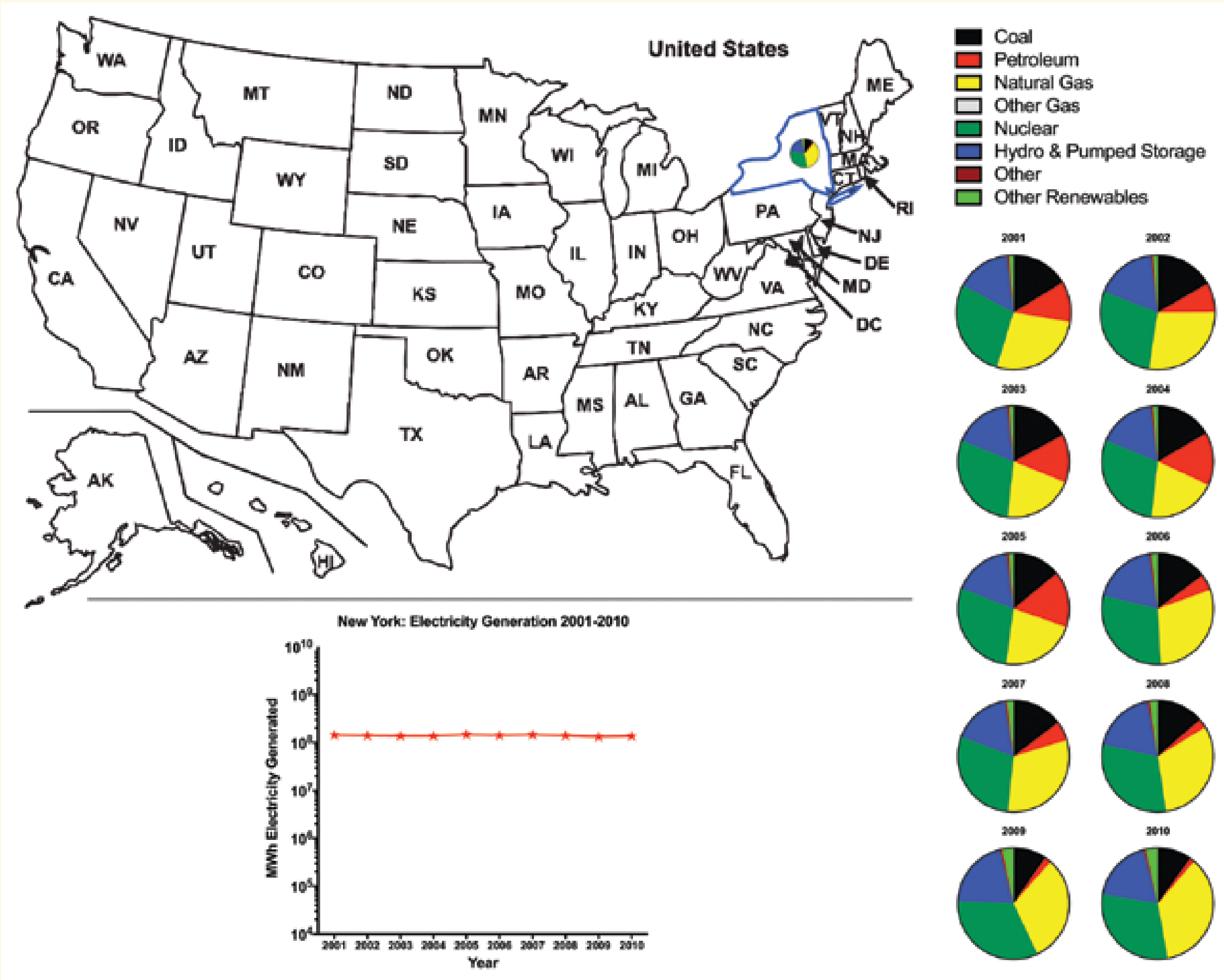
- Should we subsidize renewable energy?
- How will our transportation systems change?
- How do we deal with the variability of electricity output from renewable energy sources like wind and solar when power demand is consistent?
- Can we develop battery technology to store energy during low-demand periods?

These questions have no easy answers. Making energy choices means considering multiple factors, exploring competing ideas, and reaching conclusions based on the best available evidence.

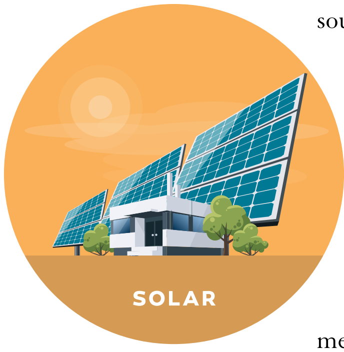
This article describes a five-day online energy module (see "On the web"), developed by the Concord Consortium (an educational research and development organization) in which students compare the effects of various energy sources on air quality, water quality, and land use. The module's interactive models explore hydraulic fracturing, real-world data on energy production and consumption, and scaffolded argumentation tasks to help students examine evidence and discuss the issues associated with claims based on models and data. The free module, which aligns with the *Next Generation Science Standards* (NGSS Lead States 2013; see box p. 68), runs on computers or tablets.

FIGURE 1

How electricity sources for New York have changed from 2001 to 2010.



CONCORD CONSORTIUM, BASED ON DATA FROM U.S. ENERGY INFORMATION ADMINISTRATION



Arguing with evidence

Scientific argumentation has been defined as making and defending claims with supporting evidence (Berland and McNeill 2010; Osborne 2010). Science teachers increasingly focus on developing students' argumentation skills. A scientific argument typically includes:

- the *claim*—a conjecture, conclusion, principle, or answer to a research question;
- *evidence*—data or findings from students that have been collected and analyzed; and
- *reasoning*—statements that explain the importance and relevance of the evidence and how the evidence supports the claim (McNeill and Krajcik 2007).

In the energy module, students construct scientific arguments based on this claim, evidence, and reasoning (CER) framework (McNeill and Krajcik 2007). Additionally, students characterize and consider the limitations of evidence from the models and data when developing their arguments, which is known as *uncertainty-infused scientific argumentation* (Lee et al. 2010).

Our energy choices have direct and indirect effects on our health, environment, and economy. The United States uses coal, oil, natural gas, nuclear fuel, hydroelectric dams, and renewable resources to generate electricity. Each source has advantages and disadvantages. Students must carefully examine the evidence when considering complex, nuanced questions such as: "Will we have enough affordable energy in the near future?"

Comparing electricity sources

The energy module first asks students, working in groups of two or three, to analyze an interactive map of electricity sources from 2001–2010 to determine the sources used in their own state. Pie charts (Figure 1) allow students to identify changes in each state's sources of electricity and to quickly compare electricity sources in different states.

Next, students compare electricity use in the United States with that in the rest of the world. The module asks: With a growing global population and an increased demand for electricity, how can we continue to meet the demand while minimizing negative environmental impacts?

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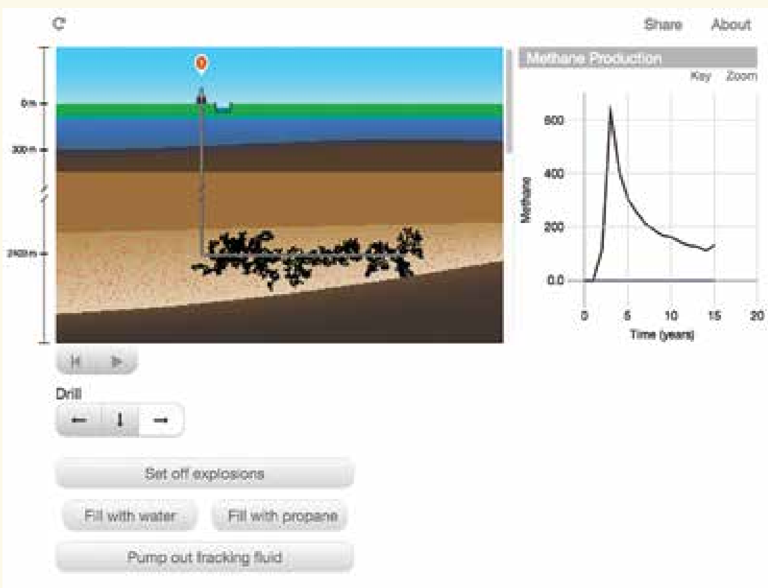
Teaching hydraulic fracturing

In the second and third activities, students learn about *hydraulic fracturing*, or "fracking," a method of extracting natural gas from shale, to make evidence-based arguments about

FIGURE 2

This model allows students to extract natural gas from shale using directional drilling and hydraulic fracturing methods.



CONCORD CONSORTIUM

energy choices. Research suggests that natural gas, a cleaner fuel than coal or oil, could lead to a "greener" energy future.

The United States recently became the largest producer of natural gas worldwide due to horizontal drilling and fracking, according to the Energy Information Administration (EIA 2014). As of May 2016, 67% of all natural gas in the United States came from hydraulically fractured wells (EIA 2016). There are 8.727 trillion cubic meters (308.2 trillion cubic feet) of proved natural gas deposits in the United States—enough to provide electricity to U.S. homes for 31 years at the current rate of natural gas electricity generation and for 11 years if all electricity were generated by natural gas—and as much as six times that in unproved deposits (EIA 2015). Fracking has become contentious in the United States. It could harm the environment, even though it is cleaner and cheaper than coal.

The curriculum aims to help students switch from gut responses about fracked natural gas and other energy sources to an analytical approach in which they consider the pros and cons of each energy choice. Students use interactive models (Figure 2, p. 63) and real-world data to learn how shale gas is extracted. They also evaluate the environmental impact of using shale gas to generate electricity. Students consider the effect of pollutants entering the atmosphere as a result of natural gas, the potential release of methane into the atmosphere during the drilling process, the impact of fracking sites on the surface, and the ways in which drilling could affect the underground water supply. Students could also investigate potential correlations between fracking and increased earthquake activity.

Evaluating and exploring energy

In the fourth activity, students evaluate other energy sources by analyzing data on air quality, land use and habitat disruption, water use and water quality, and the relative cost of energy. Finally, in the fifth activity, students explore energy efficiency.

Throughout the module, students must consider multiple pieces of evidence. For instance, when considering how electricity-generating sources affect air quality, one might choose renewable sources because they produce fewer emissions. Similarly, if considering mostly cost, students might conclude that cheap fossil fuel plants were the best choice. When considering multiple factors, however, a cost-effective source that is less harmful to the environment emerges as the priority. That's why it is essential to consider everything—environmental impacts, demand, and price—to make prudent, evidence-based arguments about energy sources.

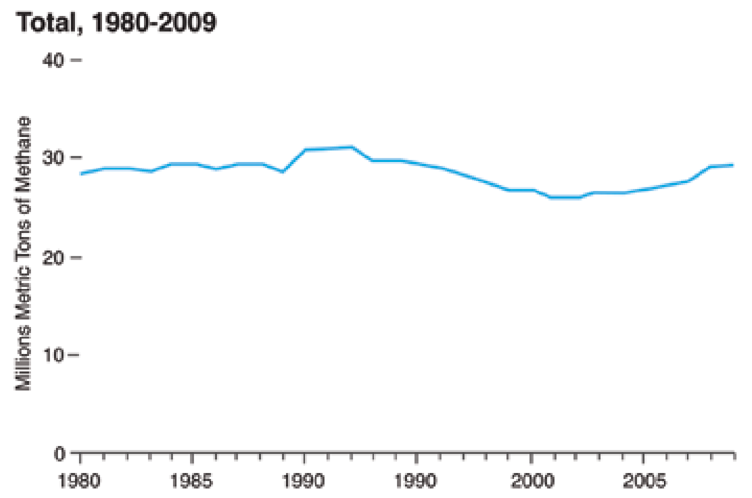
Strategies for scientific arguments

To help students with the complexity of the energy question, we embedded eight four-part argumentation tasks in the energy module. In each argumentation task, students are asked to:

1. make a claim (claim);
2. explain the claim based on evidence (explanation and reasoning);
3. express their level of certainty with the claim and evidence (certainty rating); and
4. describe their sources of certainty (certainty rationale).

FIGURE 3

An example of an argumentation task.



5) What will happen to the atmospheric methane level in the future as more natural gas wells are drilled?

The methane level will

- increase.
- decrease.
- stay about the same.

6) Explain your answer.

7) How certain are you about your claim based on your explanation?

- (1) Not at all certain
- (2)
- (3)
- (4)
- (5) Very certain

8) Explain what influenced your certainty rating.

U.S. ENERGY INFORMATION ADMINISTRATION ANNUAL ENERGY REVIEW 2011, TABLE 11.3.

In one argumentation task (Figure 3), students view a graph of atmospheric methane levels in the United States from 1980 to 2009 provided by the U.S. Energy Information Administration and are told that hydraulic fracturing for natural gas began in Texas in the 1990s and in the Marcellus Shale of Pennsylvania in 2007. Students are asked to predict future methane levels in the United States as more natural gas wells are drilled.

Although the argumentation task has four items, it is best considered as a whole. The explanation justifies the claim based on students' understandings and interpretations of data. Because the data sets are limited, students are inevitably unsure about parts of their answers. Additionally, the science behind the questions may be uncertain, as scientists are still collecting and analyzing data about energy sources. The certainty rating and certainty rationale allow students to report their claims and explain the reasons for their uncertainty.

Students must consider multiple pieces of evidence. If considering air quality, one might choose renewable sources because they produce fewer emissions. If considering mostly cost, students might conclude that cheap fossil fuel plants were the best choice.

FIGURE 4

Rubric for students' explanations.

	Description	Sample answers for methane argumentation task
Level 0	Students write "I don't know" or are off task.	I'm not sure. I don't know. I just pick anything.
Level 1	Students' explanations include only incorrect evidence from the graph or data shown.	The graph shows a slow decrease.
Level 2	Students include evidence from the graph but do not support their claim with evidence.	The more we drill, the more that will get released into the atmosphere. Looking at the graph from 1980 on up to 2009, the million metric tons of methane have not changed much but have stayed the same.
Level 3	Students identify adequate evidence to support claim.	Hydraulic fracturing started in the 1990s, and there seems to be no increase due to that drilling. More fracking happened in 2007, and there wasn't much change after that either.
Level 4	Students use theory or established knowledge to identify detailed evidence to support claim.	The more we drill for gas, the more potential to put more methane into the air. There's an increase in the methane level since 2007, which means that methane must have escaped from the drilling.
Level 5	Students use theory or established knowledge to identify comprehensive evidence to support claim.	The graph shows that there is not much change in the methane level since fracking started. There is a little bit of an increase since 2007, so this suggests that increased drilling only minorly affects the methane level. Most of the gas that they are drilling is probably captured. But if there are leaks, the increased drilling can increase the methane levels.

Students then interpret the data in the graph showing that the methane level has remained mostly steady since 1980, despite more hydraulic fracturing. One student explained: "According to the graph, the Marcellus Shale drilling in Pennsylvania has led to an upturn in the graph. I think that the line following will continue to go up because of this."

Another student responded: "From 1980 to 2005, the amount of methane has neither decreased or increased in the graph."

Based on the data in the graph, students can reason that fracking must not be the only source for atmospheric methane. How many of those sources are natural (unrelated to human actions)? How much of the methane is attributable to natural gas drilling (not just from fracking)? The next prompts ask students to consider their levels of certainty about their claim and explanation.

Students can note that the data in the graph only goes to 2009, just two years after widespread hydraulic fracturing started in Pennsylvania. They can observe that it is difficult to predict what future methane levels might be. As an extension, students can conduct further research to discover evidence of increasing atmospheric methane since 2009 (See "On the web"). Examples of students' certainty rationales include:

"I'd like to know the exact year Texas began horizontal drilling and hydraulic fracturing. It would change my answer if I knew they started in the early 1990s."

"Actions can be taken to reduce the amount of methane in the air. Also, other fuel sources may be located making natural gas obsolete."

"You can see on the graph that methane levels are gradually increasing. Then, if we get more drilling sites, there will be an even larger increase because we are extracting more methane to the surface."

FIGURE 5

Rubric for certainty rationale.

	Category	Sample answers for methane argumentation task
Level 0	No information: Students wrote "I don't know," wrote an off-task response or restated the claim.	I'm not really sure.
Level 1	Certainty related to personal skills and knowledge: Students did not understand the question, did not possess general knowledge or ability, or did not make sense of the data.	I'm not positive about the Earth and how everything works. I do not know much about this topic.
Level 2	Certainty based on science provided by the curriculum: Students referred to or elaborated on scientific knowledge or data.	The more drilling that is done, the more methane gas is going to be released. Drilling began in the 1990s, and the graph shows that the levels did not either drastically rise or fall after that time period.
Level 3	Certainty related to factors beyond what was provided by curriculum: Students recognize limitations of data, elaborate why scientific phenomena addressed are uncertain, or mention current state of scientific knowledge or data collection are limited.	The amount of methane could also increase if we use more of it. I can't be too sure whether methane would be absorbed by the same carbon sinks as carbon. But I am pretty sure that the methane would go into the atmosphere. To make money they need that methane so they're not going to let it go. So they are going to take every precaution necessary. I'd like to know the exact year Texas began horizontal drilling and hydraulic fracturing. It would change my answer if I knew they started in the early 1990s.

Evaluating arguments

Using the argumentation task in Figure 3 (p. 64) as an example, we can characterize students' argumentation performances. Students' explanations of claims and certainty rationales are scored with separate rubrics (Figures 4, p. 65, and 5, respectively). The more evidence students use and the more they consider limitations of the data, the more sophisticated their scientific arguments and the higher their scores.

Conclusion

We analyzed pre- and post-test responses to claim, explanation, certainty rating, and certainty rationale items for 1,573 students from three middle schools and seven high schools. After using the energy module, students significantly improved their scientific argumentation abilities. Today's students will have to make many important decisions about environmental issues over the course of their lives. Decisions are best made when one carefully considers all of the evidence, weighing the pros and cons of each choice, and evaluating confidence levels. By focusing on scientific arguments, teachers can help students make rational, informed decisions about energy sources in the future. ■

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Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. DRL-0929774 and DRL-1220756.

On the web

Atmospheric methane levels: *http://bit.ly/NOAA-methane*

Concord Consortium online energy module: *http://activities.concord.org/sequences/123*

Teacher guide: *http://nationalgeographic.org/lesson/what-are-our-energy-choices*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

Standards
HS-ESS3 A: Natural Resources

Performance Expectations
The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectations listed below.
HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

Dimension	Name and *NGSS* code/citation	Specific connections to classroom activity
Science and Engineering Practices	**Developing and Using Models** • Develop and use a model to describe phenomena. • Develop a model to describe unobservable mechanisms. • Use a model to provide mechanistic accounts of phenomena. **Constructing Explanations and Designing Solutions** • Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review). (HS-ESS3-1) **Analyzing and Interpreting Data** • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. **Engaging in Argument From Evidence** • Construct an oral and written argument or counter argument based on data and evidence.	Students use online interactive models to explore how hydraulic fracturing releases natural gas from deep shale formations. Students use an interactive computational model and real-world data to evaluate the environmental impact of extracting natural gas to generate electricity. Students interpret and analyze graphs and tables of real-world data to compare the costs and benefits of various sources of energy (natural gas, coal, nuclear, biomass, wind, hydro, solar). Students develop scientific arguments about the relative environmental and monetary costs of using different sources of energy (natural gas, nuclear, biomass, wind, hydro, solar) to generate electricity.
Disciplinary Core Idea	**ESS3.A: Natural Resources** • Resource availability has guided the development of human society. (HS-ESS3-1) • All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks and benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2)	Students investigate different energy sources and how they produce electricity. Students compare the energy density of different energy sources and analyze the advantages and disadvantages of renewable and nonrenewable resources. Students describe and contrast the negative effects of different electricity-generating sources on water quality and availability, air quality, and local habitats.
Crosscutting Concepts	**Cause and Effect** • Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS3-1)	Students use data to explore the correlation between energy usage and environmental impacts.