| **Unit Summary** |
|---|
| ***How is energy generated for human activity?*** <br> In this unit of study, students *engage in argument from evidence, develop and use models, ask questions and define problems, construct explanations and design solutions,* and *evaluate information*. This unit focuses on the physics core ideas surrounding energy and energy transformations as related to the Earth System core idea of energy needs for human activity. Students 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. They apply engineering design principles to design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. Within this unit students also apply the core ideas of related to the behavior of electromagnetic energy to evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. They develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction (*secondary concept*). They apply these core ideas to communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. At the basis of our energy needs is the need for resources to create energy, and therefore students evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios. The crosscutting concepts of *systems and system models*, *energy and matter*, *cause and effect*, and *stability and change* are called out as an organizing concept for these disciplinary core ideas. <br> This unit is based on HS-ESS3-2, HS-PS3-1, HS-PS3-2, HS-PS3-3, *HS-PS3-5* (secondary to HS-PS3-3), HS-PS4-3, and HS-PS4-5. <br> *[Note: The disciplinary core ideas, science and engineering practices, and crosscutting concepts can be taught in either this course or in a high school physics course.]* |
| **Student Learning Objectives** |
| **Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.** *[Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]* **(HS-ESS3-2)** |
| **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.** *[Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]* **(HS-PS3-1)** |
| **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 position of particles (objects).** *[Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]* **(HS-PS3-2)** |
| **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** *[Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency. Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]* **(HS-PS3-3)** |

| |
|---|
| *(Secondary to HS-PS3-3)* **Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.** *[Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]* **(HS-PS3-5)** |
| **Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.** *[Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.]* [Assessment Boundary: Assessment does not include using quantum theory.] **(HS-PS4-3)** |
| **Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*** *[Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.]* **(HS-PS4-5)** |

**Quick Links**



**Part A:** *What is the best energy source for a home? How would I meet the energy needs of a house of the future?*

| Concepts | Formative Assessment |
|---|---|
| • 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.<br>• Models can be used to simulate systems and interactions, including energy, matter, and information flows, within and between systems at different scales.<br>• Engineers continuously modify design solutions to increase benefits while decreasing costs and risks.<br>• Analysis of costs and benefits is a critical aspect of decisions about technology.<br>• Scientific knowledge indicates what can happen in natural systems, not what should happen. The latter involves ethics, values, and human decisions about | *Students who understand the concepts are able to:*<br>• Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations).<br>• Use models to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost–benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations). |

| | |
|---|---|
| the use of knowledge.<br>• New technologies can have deep impacts on society and the environment, including some that were not anticipated.<br>• Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.<br>• Many decisions are made not using science alone, but instead relying on social and cultural contexts to resolve issues. | |

**Part B:** *How can we use mathematics in decision-making about energy resources?*

| Concepts | Formative Assessment |
|---|---|
| • 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.<br>• 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.<br>• Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.<br>• The availability of energy limits what can occur in any system.<br>• Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximation inherent in models.<br>• Science assumes that the universe is a vast single system in which basic laws are consistent. | *Students who understand the concepts are able to:*<br>• Use basic algebraic expressions or computations to create a computational model to calculate the change in the energy of one component in a system (limited to two or three components) when the change in energy of the other component(s) and energy flows in and out of the system are known.<br>• Explain the meaning of mathematical expressions used to model the change in the energy of one component in a system (limited to two or three components) when the change in energy of the other component(s) and out of the system are known. |

**Part C:** *I have heard about it since kindergarten but what is energy?*

| Concepts | Formative Assessment |
|---|---|
| • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system.<br>• At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.<br>• These relationships are better understood at the microscopic scale, at which | *Students who understand the concepts are able to:*<br>• Develop and use models based on evidence to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects). |

| | |
|---|---|
| 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).<br>• In some cases, the relative position energy can be thought of as stored in fields (which mediate interactions between particles).<br>• Radiation is a phenomenon in which energy stored in fields moves across spaces.<br>• Energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. | • Develop and use models based on evidence to illustrate that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems.<br>• Use mathematical expressions to quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compressions of a spring) and how kinetic energy depends on mass and speed.<br>• Use mathematical expressions and the concept of conservation of energy to predict and describe system behavior. |

**Part D:** *Superstorm Sandy devastated the New Jersey Shore and demonstrated to the public how vulnerable our infrastructure is. Using your understandings of energy, design a low technology system that would insure the availability of energy to residents if catastrophic damage to the grid occurs again.*

| Concepts | Formative Assessment |
|---|---|
| • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.<br>• Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.<br>• 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.<br>• 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.<br>• News technologies can have deep impacts on society and the environment, including some that were not anticipated.<br>• Analysis of costs and benefits is a critical aspect of decisions about technology.<br>• Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.<br>• Humanity faces major global challenges today, such as the need for supplies | *Students who understand the concepts are able to:*<br>• Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.<br>• Analyze a device to convert one form of energy into another form of energy by specifying criteria and constraints for successful solutions.<br>• Use mathematical models and/or computer simulations to predict the effects of a device that converts one form of energy into another form of energy. |

| | |
|---|---|
| of clean water or for energy sources that minimize pollution that can be addressed through engineering. These global challenges also may have manifestations in local communities. | |

| **Part E:** *How can electromagnetic radiation be both a wave and a particle at the same time?* | |
|---|---|
| **Concepts** | **Formative Assessment** |
| • Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other.<br>• Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.<br>• A wave model or a particle model (e.g., physical, mathematical, computer models) can be used to describe electromagnetic radiation—including energy, matter, and information flows—within and between systems at different scales.<br>• A wave model and a particle model of electromagnetic radiation are based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. | *Students who understand the concepts are able to:*<br>• Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other.<br>• Evaluate experimental evidence that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other.<br>• Use models (e.g., physical, mathematical, computer models) to simulate electromagnetic radiation systems and interactions—including energy, matter, and information flows—within and between systems at different scales. |

| **Part F:** *How does the International Space Station power all of its equipment? How do astronauts communicate with people on the ground?* | |
|---|---|
| **Concepts** | **Formative Assessment** |
| • Solar cells are human-made devices that capture the sun's energy and produce electrical energy.<br>• Photoelectric materials emit electrons when they absorb light of a high enough frequency.<br>• Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information | *Students who understand the concepts are able to:*<br>• Communicate qualitative technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.<br>• Communicate technical information or ideas about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy in multiple formats (including orally, graphically, textually, and mathematically).<br>• Analyze technological devices that use the principles of wave behavior |

| | |
|---|---|
| contained in them.<br>• Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.<br>• Humanity faces major global challenges today, such as the need for supplies of clean water and food and for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.<br>• 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.<br>• Wave interaction with matter systems can be designed to transmit and capture information and energy.<br>• Science and engineering complement each other in the cycle known as research and development (R&D).<br>• Modern civilization depends on major technological systems.<br>• 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. | and wave interactions with matter to transmit and capture information and energy by specifying criteria and constraints for successful solutions.<br>• Evaluate a solution offered by technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. |

| **What it Looks Like in the Classroom** |
|---|
| In this unit, students explore the disciplinary core ideas around energy resources while applying core ideas from physical science related to energy. Working from the premise that all forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs, risks, and benefits, students use cost–benefit ratios to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources. For example, students might investigate the real-world technique of using hydraulic fracturing to extract natural gas from shale deposits versus other traditional means of acquiring energy from natural resources. Students will synthesize information from a range of sources into a coherent understanding of competing design solutions for extracting and utilizing energy and mineral resources. As students evaluate competing design solutions, they should consider that new technologies could have deep impacts on society and the environment, including some that were not anticipated. Some of these impacts could raise ethical issues for which science does not provide answers or solutions. In their evaluations, students should make sense of quantities and relationships associated with developing, managing, and utilizing energy and mineral resources. Mathematical models can be used to explain their evaluations. Students might represent their understanding by conducting a Socratic seminar as a way to present opposing views. Students should consider and discuss decisions about designs in scientific, social, and cultural contexts.<br><br>Related to the integration of physical science core ideas, the following classroom methods may be applied; however the big idea centered on our energy resources is in the forefront throughout the unit.<br><br>Students will develop an understanding that energy is a quantitative property. They will explore energy in systems as a function of the motion and interactions of |

matter and radiation within systems. Energy can be detected and measured at the macroscopic scale as the phenomena of motion, sound, light, and thermal energy. Students will also learn that these forms of energy can be modeled in terms of the energy associated with the motion of particles or the energy stored in fields (gravitational, electric, magnetic,) that mediate interactions between particles.

Students are ultimately able to develop models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles, or objects, and energy associated with the relative position of particles, or objects. In some cases, the relative position energy can be thought of as stored in fields. Students should be able to qualitatively show that an object in a gravitational field has a greater amount of potential energy as it is put into higher and higher locations in that field. An example of this could be investigating how an object, such as a ball, when released from successively higher and higher positions hits the ground at greater and greater velocities (kinetic energy).

| | |
|---|---|
| Kinetic Energy | $\text{KE}=\frac{1}{2}mv^2$ |
| Potential Energy | $PE_{gravitational} = mgh$ |
| Work | $W = Fd$ |

In these kinds of investigations, students should understand how to obtain the original potential energy of the object. They should know that when work is done on an object, the energy of the object changes, such as when the wrecking ball of a demolition machine is raised. Work can be calculated ($W$=$Fd$), appreciated, and understood as a concept. Students should recognize the relationship between the work done on an object and the potential energy of objects. Considering an object that collides with the ground, students should be able to list a variety of ways the kinetic energy is transferred upon impact. For example, kinetic energy is transferred to thermal energy or to sound. Emphasis on the law of conservation of energy should be evident at all points of this discussion. Energy cannot be created or destroyed. It only moves between one place and another, between objects and/or fields, or between systems. Students should demonstrate their understanding of energy conservation and transfer using models. Models should be evidence based and illustrate the relationship between energy at the bulk scale and motion and position at the particle scale. Models should also illustrate conservation of energy. Examples of models might include diagrams, drawings, written descriptions, or computer simulations. Modeling should include strategic use of digital media in presentations to enhance understanding.

Students should understand that changes of energy in a system are described in terms of energy flows into, out of, and within the system. They should also be able to describe the components of a system. Basic algebraic expressions or computations should be used to model the energy of one component of a system (limited to two or three components) when the change in energy of the other components is known. At this point, the law of conservation of energy should be evident numerically through analysis of calculated data.

Students also should use mathematical expressions to quantify how stored energy in a system depends on configuration—for example, the stretching or compression of a spring. Students might calculate the potential energy of springs. Students should also consider how stored energy depends on configuration in terms of relative positions of charged particles. Students might perform investigations with capacitors. They should also know that the availability of energy limits what can occur in any system.

Another way for students to illustrate that, in systems, energy can be transformed into various types of energy (both potential and kinetic) is to describe and diagram the changes in energy that occur in systems. For example, students could diagram steps showing the transformations of energy that occur when a student uses a yo-yo or the transformations of energy that occur in a burning candle. Ultimately, students might also diagram the steps showing transformations of energy, from fusion in the sun to the food that we eat. Students should include the phenomenon of radiation, in which energy stored in fields can move across spaces, when appropriate.

In this unit, students will also design, build, and refine a device that works within given constraints to convert one form of energy into another based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. They should also use mathematical models or computer simulations to predict the effects of a device that converts one form of energy into another.

To fulfill the engineering component of this unit as described above, students might be assigned an energy project to explore energy transformation and conservation. This could be a computer simulation, practical model, or model with Excel-calculated formulae to verify expected results. Students could also design and build a Rube Goldberg apparatus to perform a given task. After conducting research, students could make claims or defend arguments about various green energy sources. Properties of dams, solar cells, solar ovens, generators, and turbines could be explored through simulations. Evaluations of devices should be both qualitative and quantitative, and analysis of costs and benefits is a critical aspect of design decisions.

When focusing on engineering, students keep in mind that modern civilization depends on major technological systems, and that engineers continuously modify these systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Students should also develop an understanding that new technologies can have deep impacts on society and the environment, including some that were not anticipated.

The suggested methods that follow focus on the PE's related to waves and electromagnetic energy.

Students are then introduced to the idea that electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. Students should have an understanding of the wave model from their work in the previous unit. Because all observations cannot be explained with one model, students should explore the wave and particle models and make determinations about which is most appropriate in which situations. Students might begin the unit by exploring the history of the wave and particle models. In their research, students should evaluate the hypotheses, data, analysis, and conclusions in text and cite evidence to support their analysis. Students should also be able to support claims, evidence, and reasoning with mathematical expressions representing wave and particle models of electromagnetic radiation, rearranging formulas to highlight a quantity of interest, and making sense of quantities and relationships.

Students must be able to determine which model is most appropriate under which circumstances by evaluating experimental evidence, claims, evidence, and reasoning. Students may research this question and present their findings in an argumentative essay. Students might consider particular phenomena, such as diffraction, and determine whether the wave or particle model provides the best explanation. Using a Venn diagram, students could differentiate between phenomena and models. Students use models (e.g., physical, mathematical, computer models) to simulate electromagnetic radiation systems and interactions.

Some **wave** applications include:

- Diffraction—Students can be shown how waves bend around obstacles in a wave tank or explore using a prism and a laser.
- Polarization—Students could explore this phenomenon through its use in 3D movies, computer monitors, cell phones, and sunglasses.
- Doppler shift—Students can consider applications of Doppler shift in astronomy and weather.
- Wave interference—A wave tank or computer simulation could be used to illustrate interference.
- Transmission—Wave transmission can be modeled using computer simulations.

Some **particle** applications include:

- Refraction—Students can explore light bending as changes in media using prisms or water. They can also use Snell's Law to describe the relationship between angles of incidence and refraction.

- Reflection—Students should develop an understanding of incident rays and reflected rays using the law of reflection. They might explore this concept using a wave tank.
- Ray diagrams—Students can create lens ray diagrams on paper.
- Photoelectric effect—Students can explore solar cells to understand this phenomenon. Note that if this course is sequenced before chemistry, students will not have an understanding of electrons.
- Piezoelectric effect—Students might research this phenomenon using solar cells and ultrasound analogies.

Students understand that the energy in a wave depends on its frequency as well as its amplitude (energy is proportional to amplitude squared). Different frequencies of electromagnetic radiation also have different abilities to penetrate matter. When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. For example ultraviolet light penetrates the skin and can cause skin cancer, while X-rays and gamma rays can permeate deep tissue and cause radiation poisoning. Students should explore these cause-and-effect relationships through an investigation of scientific text. They should cite evidence from multiple sources; evaluate hypotheses, data, analysis, and conclusions; and assess strengths and limitations.

To explore color and energy, students could explore Herschel's experiment in which thermometers were placed in different colors to see which color was "hottest." It turned out that Herschel's control, placed in what is now known as infrared, was the hottest of all. This demonstrated that there are wavelengths of electromagnetic radiation beyond the visible spectrum.

Students research how different spectra of light interact with matter, such as the effects of electromagnetic radiation on the human body—effects of nuclear disasters on plant workers (Chernobyl, Fukushima, Three Mile Island), skin cancer, medical X-rays, diagnostic imaging technology, etc. Specifically, they should evaluate the validity and reliability of source material and determine cause-and-effect relationships. The final product could be a written essay, presentation, model, or oral debate. Research topics might include:

The engineering component of this unit includes exploring how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. Students might investigate solar cells and how they work, including a qualitative description of the photoelectric effect. Photoelectric materials emit electrons when they absorb light of a high enough frequency. This is another opportunity to discuss solar cells. Other technologies that use the photoelectric effect include automatic doors, safety lights, television camera tubes, light-activated counters, intrusion alarms, and streetlights.

Students evaluate the efficiency and cost-effectiveness of modern solar cell technology. Given existing solar cells, students may consider how they rate in terms of one-time purchase, aesthetics, maintenance, and overall total cost of ownership. They evaluate this energy solution scientific knowledge, student- generated sources of evidence, prioritized criteria, and tradeoff considerations.

The advantages and disadvantages of various electromagnetic frequencies in modern technology are explored using examples such as astronomical telescopes (microwave, infrared, visible, etc.), LiDAR, solar panel cells, CDs, Blu-ray, infrared remote controls or car fobs, infrared motion detection cameras, computer memory storage, or fiber optics. Students create models of the interactions in these common types of systems and explain their model using either written or oral media.

*Integration of engineering-*

Students communicate technical information comparing energy resources while integrating their knowledge of physical science and energy transformations. ETS1-1 and ETS1-3 are identified as appropriate connections so that students can analyze a major global challenge and evaluate a solution to a complex real-world problem.

*Integration of PE's and DCI's from other units-*

This unit ties in with the physical science model curriculum units on energy (Unit 4) and on waves (Unit 7) as they pertain to energy resources. Refer to those units for additional classroom integration methods. Additionally, consider linking the performance expectation related to nuclear energy with this unit (HS-PS1-8).

**Leveraging English Language Arts/Literacy and Mathematics**

*English Language Art/Literacy*

- Collect relevant data across a broad spectrum of sources about the distribution of energy in a system and assess the strengths and limitations of each source.
- Synthesize findings from experimental data into a coherent understanding of energy distribution in a system.
- Cite specific textual evidence to evaluate competing design solutions for developing, managing, and utilizing energy resources based on cost–benefit ratios.
- Evaluate the hypotheses, data, analysis, and conclusions of competing design solutions for developing, managing, and utilizing energy resources based on cost–benefit ratios, verifying the data when possible and corroborating or challenging conclusions with other design solutions.
- Integrate and evaluate multiple design solutions for developing, managing, and utilizing energy resources based on cost–benefit ratios in order to reveal meaningful patterns and trends.
- Evaluate the hypotheses, data, analysis, and conclusions of competing design solutions for developing, managing, and utilizing energy resources based on cost–benefit ratios, verifying the data when possible and corroborating or challenging conclusions with other design solutions.
- Synthesize data from multiple sources of information in order to create data sets that inform design decisions and create a coherent understanding of developing, managing, and utilizing energy resources.
- Make strategic use of digital media in presentations to enhance understanding of the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Make strategic use of digital media in presentations to support the claim that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects).
- Conduct short as well as more sustained research projects to describe energy conversions as energy flows into, out of, and within systems.
- Integrate and evaluate multiple sources of information presented in diverse formats and media to describe energy conversions as energy flows into, out of, and within systems.
- Evaluate scientific text regarding energy conversions to determine the validity of the claim that although energy cannot be destroyed, it can be converted into less useful forms.
- Assess the extent to which the reasoning and evidence in a text supports the author's claim that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
- Cite specific textual evidence to support the wave model or particle model in describing electromagnetic radiation, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text relating that electromagnetic radiation can be described either by a wave

model or a particle model and that for some situations one model is more useful than the other, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

- Assess the extent to which the reasoning and evidence in a text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter support the author's claim or recommendation.
- Cite textual evidence to support analysis of science and technical texts describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., qualitative data, video multimedia) in order to address the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Gather relevant information from multiple authoritative print and digital sources describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
- Write informative/explanatory texts about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, including the narration of scientific procedures, experiments, or technical processes.
- Integrate and evaluate multiple sources of information about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, presented in diverse formats and media (e.g., quantitative data, video, multimedia), in order to address a question or solve a problem.

*Mathematics*

- Use a mathematical model to describe energy distribution in a system when two components of different temperature are combined. Identify important quantities in energy distribution in a system when two components of different temperature are combined and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of the properties of water and their effects on Earth materials and surface processes.
- Use symbols to represent an explanation of the best of multiple design solutions for developing, managing, and utilizing energy and mineral resources and manipulate the representing symbols. Make sense of quantities and relationships in cost–benefit ratios for multiple design solutions for developing, managing, and utilizing energy and mineral resources symbolically and manipulate the representing symbols.
- Use a mathematical model to explain the evaluation of multiple design solutions for developing, managing, and utilizing energy and mineral resources. Identify important quantities in cost–benefit ratios for multiple design solutions for developing, managing, and utilizing energy and mineral resources and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent symbolically an explanation about the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known, and manipulate the

representing symbols. Make sense of quantities and relationships about 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 symbolically, and manipulate the representing symbols.

- Use a mathematical model to explain the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known. Identify important quantities in energy of components in systems and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand how the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known; choose and interpret units consistently in formulas representing how the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known; choose and interpret the scale and the origin in graphs and data displays representing that the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Represent the conversion of one form of energy into another symbolically, considering criteria and constraints, and manipulate the representing symbols. Make sense of quantities and relationships in the conversion of one form of energy into another.
- Use a mathematical model of how energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects). Identify important quantities representing how the energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects), and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use a mathematical model to describe the conversion of one form of energy into another and to predict the effects of the design on systems and/or interactions between systems. Identify important quantities in the conversion of one form of energy into another and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand the conversion of one form of energy into another; choose and interpret units consistently in formulas representing energy conversions as energy flows into, out of, and within systems; choose and interpret the scale and the origin in graphs and data displays representing energy conversions as energy flows into, out of, and within systems.
- Define appropriate quantities for the purpose of descriptive modeling of a device to convert one form of energy into another form of energy.
- Represent symbolically that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other, and manipulate the representing symbols.
- Make sense of quantities and relationships between the wave model and the particle model of electromagnetic radiation.
- Interpret expressions that represent the wave model and particle model of electromagnetic radiation in terms of the usefulness of the model depending on the situation.
- Choose and produce an equivalent form of an expression to reveal and explain properties of electromagnetic radiation.
- Rearrange formulas representing electromagnetic radiation to highlight a quantity of interest, using the same reasoning as in solving equations.
- Represent the principles of wave behavior and wave interactions with matter to transmit and capture energy symbolically, considering criteria and constraints, and manipulate the representing symbols. Make sense of quantities and relationships in the principles of wave behavior and wave interactions with matter to

transmit and capture energy.

- Use a mathematical model to describe the principles of wave behavior and wave interactions with matter to transmit and capture information and energy and to predict the effects of the design on systems and/or interactions between systems. Identify important quantities in the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

**Modifications**

*(Note: Teachers identify the modifications that they will use in the unit. See NGSS Appendix D: All Standards, All Students/Case Studies for vignettes and explanations of the modifications.)*

- Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community.
- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences).
- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.
- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.
- Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA).

**Research on Student Learning**

Students rarely think energy is measurable and quantifiable. Students' alternative conceptualizations of energy influence their interpretations of textbook representations of energy.

Students tend to think that energy transformations involve only one form of energy at a time. Although they develop some skill in identifying different forms of energy, in most cases their descriptions of energy-change focus only on forms which have perceivable effects. The transformation of motion to heat seems to be difficult for students to accept, especially in cases with no temperature increase. Finally, it may not be clear to students that some forms of energy, such as light, sound, and chemical energy, can be used to make things happen.

The idea of energy conservation seems counterintuitive to students who hold on to the everyday use of the term energy, but teaching heat dissipation ideas at the same time as energy conservation ideas may help alleviate this difficulty. Even after instruction, however, students do not seem to appreciate that energy conservation is a useful way to explain phenomena. A key difficulty students have in understanding conservation appears to derive from not considering the appropriate system and environment. In addition, high-school students tend to use their conceptualizations of energy to interpret energy conservation ideas. For example, some students interpret the idea that "energy is not created or destroyed" to mean that energy is stored up in the system and can even be released again in its original form. Or, students may believe that no energy remains at the end of a process, but may say that "energy is not lost" because an effect was caused during the process (for example, a weight was lifted). Although teaching approaches which accommodate students' difficulties about energy appear to be more successful than traditional science instruction, the main deficiencies outlined above remain despite these approaches (NSDL, 2015)

**Prior Learning**

*Physical science*

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- A system of objects may also contain stored (potential) energy, depending on their relative positions.
- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

- The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen.
- A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.
- A sound wave needs a medium through which it is transmitted.
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

*Life Science*

- Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.
- In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction.
- Growth of organisms and population increases are limited by access to resources.
- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.
- Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling.

*Earth and space science*

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.
- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.
- Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.
- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things.
- Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and

technologies involved are engineered otherwise.

**Connections to Other Courses**

*Physical science*

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.
- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- 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.
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
- 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.
- 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.
- 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 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.
- Uncontrolled systems always evolve toward more stable states— that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.
- The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis.

*Life science*

- Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

*Earth and space science*

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.
- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.
- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution

among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- Resource availability has guided the development of human society.
- 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.

**Samples of Open Education Resources for this Unit**

Carbon Stabilization Wedge: Students play this game in order to evaluate competing design solutions for developing, managing, and utilizing energy resources based on cost-benefit ratios.

One For All: A Natural Resources Game: Identify a strategy that would produce a sustainable use of resources in a simulation game. Draw parallels between the chips used in the game and renewable resources upon which people depend. Draw parallels between the actions of participants in the game and the actions of people or governments in real-world situations.

National Climate Assessment: Students explore the simulations found at this website in order to create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.

Know Your Energy Costs: The goal of this activity is to become aware of how much energy you use at school — and the financial and environmental costs.

Earth: Planet of Altered States: Watch a segment of a NASA video and discuss how the earth is constantly changing.

Climate Reanalyzer: Students use the Environmental Change Model of the Climate Reanlyzer to study the feedbacks in the climate system.

Energy Skate Park: Basics: Learn about conservation of energy with a skater gal! Explore different tracks and view the kinetic energy, potential energy and friction as she moves. Build your own tracks, ramps, and jumps for the skater.

Work and Energy Workbook Labs: The lab description pages describe the question and purpose of each lab and provide a short description of what should be included in the student lab report.

Build a Solar House: Construct and measure the energy efficiency and solar heat gain of a cardboard model house. Use a light bulb heater to imitate a real furnace and a temperature sensor to monitor and regulate the internal temperature of the house. Use a bright bulb in a gooseneck lamp to model sunlight at different times of the year, and test the effectiveness of windows for passive solar heating.

Energy Skate Park: Basics: Learn about conservation of energy with a skater gal! Explore different tracks and view the kinetic energy, potential energy and friction as she moves. Build your own tracks, ramps, and jumps for the skater.

Work and Energy Workbook Labs: The lab description pages describe the question and purpose of each lab and provide a short description of what should be included in the student lab report.

Introduction to the Electromagnetic Spectrum: NASA background resource

Technology for Imaging the Universe: NASA background resource

NASA LAUNCHPAD: Making Waves: NASA e-Clips activity on the electromagnetic spectrum

Radio Waves and Electromagnetic Fields: Phet simulation demonstrating wave generation, propagation and detection with antennas.

Refraction: https://phet.colorado.edu/en/simulation/wave-interferencePHeT simulation addressing refraction of light at an interface.

Wave Interference: Phet simulation of both mechanical and optical wave phenomena

Thin Film Interference: OSP simulation of thin film interference for various wavelengths of visible light

Photoelectric Effect Phet: Phet simulation addressing evidence for particle nature of electromagnetic radiation

Photoelectric Effect OSP: Open Source Physics simulation of the photoelectric effect.

Interaction of Molecules with Electromagnetic Radiation: Phet simulation exploring the effect of microwave, infrared, visible and ultraviolet radiation on various molecules.

Wave/Particle Dualism: Phet simulation of wave and particle views of interference phenomena.

X-ray Technology: OSP Simulation of optimization of X-ray contrast by varying energy of X-rays, materials characteristics and measurement parameters

| **Appendix A: NGSS and Foundations for the Unit** |
|---|
| **Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.** *[Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]* **(HS-ESS3-2)** |
| **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.** *[Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]* **(HS-PS3-1)** |
| **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 position of particles (objects).** *[Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]* **(HS-PS3-2)** |
| **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** *[Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency. Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]* **(HS-PS3-3)** |
| *(Secondary to HS-PS3-3)* **Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.** *[Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]* **(HS-PS3-5)** |
| **Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.** *[Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.]* [Assessment Boundary: Assessment does not include using quantum theory.] **(HS-PS4-3)** |
| **Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*** *[Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.]* **(HS-PS4-5)** |

The Student Learning Objectives above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

| Science and Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts |
|---|---|---|
| **Asking Questions and Defining Problems**<br>• Evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. (HS-PS4-2)<br>**Developing and Using Models**<br>• Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-2), (HS-PS3-5)<br>**Using Mathematics and Computational Thinking**<br>• Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-PS3-1)<br>**Constructing Explanations and Designing Solutions**<br>• 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. (HS-PS3-3)<br>**Engaging in Argument from Evidence**<br>• Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-PS4-3)<br>• Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). (HS-ESS3-2) | **ESS3.A: Natural Resources**<br>• 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)<br>**PS3.A: Definitions of Energy**<br>• 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)<br>• At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2)<br>• 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. (HS-PS3-2) | **Cause and Effect**<br>• Systems can be designed to cause a desired effect. (HS-PS4-5)<br>• Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS3-5)<br>**Systems and System Models**<br>• Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS-PS3-1)<br>• Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-PS4-3)<br>**Energy and Matter**<br>• 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. (HS-PS3-3)<br>• Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2)<br>- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -<br>***Connections to Engineering, Technology, and Applications of Science*** |

**Obtaining, Evaluating, and Communicating Information**

- Communicate technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS4-5)

**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. *(secondary to HS-ESS3-2)*

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

***Connections to Nature of Science***

**Scientific Knowledge Assumes an Order and Consistency in Natural Systems**

- Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS3-1)

**Science is a Human Endeavor**

- Science is a result of human endeavors, imagination, and creativity. (HS-ESS3-3)

**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. (HS-ESS3-2)

- 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. (HS-ESS3-

**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. (HS-PS3-1)

- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1)

- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged 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. (HS-PS3-1)

- The availability of energy limits what can occur in any system. (HS-PS3-1)

**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)

**PS3.C: Relationship between Energy and Forces**

- When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5, secondary to HS-PS3-3)

**PS4.A: Wave Properties**

- Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the

**Interdependence of Science, Engineering, and Technology**

- Science and engineering complement each other in the cycle known as research and development (R&D). (HS-PS4-5)

**Influence of Science, Engineering and Technology on Society and the Natural World**

- Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3), (HS-PS4-5)

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-ESS3-2)

- Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS3-2)

**Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena**

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. (HS-PS4-3)

| | | |
|---|---|---|
| 2)<br>• Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. (HS-ESS3-2) | fact that two different sounds can pass a location in different directions without getting mixed up.) (HS-PS4-3)<br>• Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-5)<br>**PS4.B: Electromagnetic Radiation**<br>• Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3)<br>• Photoelectric materials emit electrons when they absorb light of a high-enough frequency. (HS-PS4-5)<br>**PS3.D: Energy in Chemical Processes**<br>• Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. (secondary to HS-PS4-5) | |

| Embedded English Language Arts /Literacy | Mathematics |
|---|---|
| Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS4-3), (HS-ESS3-2) **RST.11-12.1**<br><br>Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-PS4-3),(HS-ESS3-2) **RST.11-12.8**<br><br>Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. (HS-PS4-3), **RST.9-10.8** | Reason abstractly and quantitatively. (HS-ESS3-2), (HS-PS3-1), (HS-PS3-2), (HS-PS3-3), (HS-PS3-5)**,** (HS-PS4-3) **MP.2**<br><br>Model with mathematics. (HS-PS3-1), (HS-PS3-2), (HS-PS3-3), (HS-PS3-5) **MP.4**<br><br>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. (HS-PS3-1),(HS-PS3-3) **HSN-Q.A.1**<br><br>Define appropriate quantities for the purpose of descriptive modeling. (HS-PS3-1),(HS-PS3-3) **HSN-Q.A.2** |

| | |
|---|---|
| Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. (HS-PS4-5) **WHST.11-12.2**<br><br>Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-5) **WHST.9-12.7**<br><br>Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS3-5) **WHST.11-12.8**<br><br>Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS3-5) **WHST.9-12.9**<br><br>Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-PS3-1),(HS-PS3-2),(HS-PS3-5) **SL.11-12.5** | Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS3-1),(HS-PS3-3) **HSN-Q.A.3**<br><br>Interpret expressions that represent a quantity in terms of its context. (HS-PS4-3) **HSA-SSE.A.1**<br><br>Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS4-3) **HSA-SSE.B.3**<br><br>Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS4-3) **HAS.CED.A.4** |