High School Science Domains Model Course 1-Chemistry-Bundle 4
The Materials We Need

This is the fourth bundle of the High School Domains Model Course 1-Chemistry. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 4 Question: This bundle is assembled to address the question of "How and where do we get the materials we need?"

Summary

The bundle organizes performance expectations around the theme of *the materials we need*. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

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 (ESS3.A as in HS-ESS3-2). Energy production and resource extraction connect to the ideas of water's capacity to absorb, store, and release large amounts of energy, and dissolve and transport materials (ESS2.C as in HS-ESS2-5) through the role of water in energy production and resource extraction.

The role of water in energy production and resource extraction has further connections chemical reactions through the idea that the collisions of molecules and the rearrangements of atoms into new molecules (PS1.B as in HS-PS1-5), which occur when water dissolves and transports materials (ESS2.C as in HS-ESS2-5). The ideas of chemical reactions (ESS2.C as in HS-ESS2-5) also connect to the concept that 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 (PS1.B as in HS-PS1-6).

The ideas of energy production and resource extraction (ESS3.A as in HS-ESS3-2) have connections to the concept that 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 (ETS1.B as in HS-ESS3-2). This could be accomplished through a student report reviewing methods of energy production and recommending methods based on an evaluation of their comparative costs, safety, or reliability. Alternatively, students could engage in a task that focuses on methods of mineral resource extraction, again through a student report reviewing methods and making recommendations based on an evaluation of their comparative costs, safety, or reliability.

The idea of a dynamic and condition-dependent balance between a reaction and the reverse reaction (PS1.B as in HS-PS1-6) connects to the idea that criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed (ETS1.C as in HS-PS1-6). This could be accomplished by having students engage in a task where they learn how engineers use principles of equilibrium and knowledge of chemical reactions to drive reactions to produce desired products or to increase the amount of product produced, and use this knowledge to recommend a manufacturing process that utilizes a recycled material that is reclaimed through a chemical reaction. Alternatively, students could engage in a task where they learn how engineers use principles of equilibrium and knowledge of chemical reactions to drive reactions to produce desired products or to increase the amount of product produced, and use this knowledge to recommend a manufacturing process that a material that is extracted through a chemical reaction.

The concept that criteria and constraints include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and that they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them (ETS1.A as in ETS1.1) could connect to the idea that energy production has associated economic, social, environmental, and geopolitical costs and risks as well as benefits (ESS3.A as in HS-ESS3-2). To explore this connection, students could engage in a task where they analyze a form of energy production in order to quantify the economic, social, environmental, and geopolitical risks associated with that resource. Students could propose a change to an energy production process that would meet criteria that would mitigate risks. Alternatively, students could engage in a similar task focusing on one form of energy production and on quantifying the risks associated with one risk category-either economic, social, environmental, or geopolitical. Students could propose a design change to a specific technology associated with that form of energy production based upon criteria that would mitigate risks in the identified category.

Bundle Science and Engineering Practices
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of constructing explanations and designing solutions (HS-PS1-5 and HS-PS1-6), planning and conducting an investigations (HS-ESS2-5), engaging in argument (HS-ESS3-2), and defining problems (HS-ETS1-1). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Patterns (HS-PS1-5), Stability and Change (HS-PS1-6), Structure and Function (HS-ESS2-5), and Connections to Engineering, Technology, and Applications of Science (HS-ESS3-2 and HS-ETS1-1). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations HS-ESS2-5 is partially assessable (continued in Course 2: Physics).	HS-PS1-5. **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.** **[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.]** **[*Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.*]** HS-PS1-6. **Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*** **[Clarification Statement: Emphasis is on the application of Le Hotelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.]** **[*Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.*]**

Performance Expectations (Continued)	HS-ESS2-5. **Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]** HS-ESS3-2. **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-ETS1-1. **Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.**
Example Phenomena	Bread rises faster in a warm room than in a cold room. Salt dissolves more easily in warm water than cold water. Some types of batteries can be recharged but other types of batteries cannot.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** ● Ask questions to clarify and refine a model, an explanation, or an engineering problem. Students could *ask questions to clarify* **environmental and societal constraints related to the management, utilization, and/or use of energy and mineral resources.** HS-ESS3-2 **Developing and Using Models** ● Develop a complex model that allows for manipulation and testing of a proposed process or system. Students could *create a model of a* **dynamic and condition-dependent balance between a reaction and the reverse reaction** in order to investigate the way that reaction would change under different conditions. HS-PS1-6 **Planning and Carrying Out Investigations** ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Students could *plan and conduct an investigation to collect evidence for how* **temperature affects reaction rates.** HS-PS1-5

Additional Practices Building to the PEs (Continued)	**Analyzing and Interpreting Data** ● Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. After investigating **chemical reaction rates**, students could *compare* [their data to their classmates' data or another source of data to evaluate] *the consistency of relationships observed*. HS-PS1-5 **Using Mathematics and Computational Thinking** ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. [Students could *use an algorithmic representation of a* **chemical process** to describe [a method for increasing a desired product from a chemical system]. HS-PS1-6 **Constructing Explanations and Designing Solutions** ● Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. Students could use their understanding of how the **properties of water are central to the planet's dynamics** *to explain* [how processes in the] *natural world operate today as they did in the past*. HS-PS1-6 and HS-ESS2-5 **Engaging in Argument from Evidence** ● Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence. Students could use their *evidence of* **the structure and properties of water** *in order to make and defend a claim about the* **roles of water in Earth's surface processes.** HS-ESS2-5 **Obtaining, Evaluating, and Communicating Information** ● Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. Students could *critically read scientific literature* [related to] **forms of energy production and other resource extraction** *to determine central ideas or conclusions* [about the] **associated economic, social, environmental, and geopolitical costs and risks and benefits**. HS-ESS3-2

Additional Crosscutting Concepts Building to the PEs	**Scale, Proportion, and Quantity** ● Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. Students could *use orders of magnitude to understand how models of the* **reaction and the reverse reaction in a chemical system** *at one scale relates to a model at another scale*. HS-PS1-6 **Systems and Systems Models** ● Models (e.g., physical, mathematical, computer models) can be used to simulate the flow of energy, matter, and interactions within and between systems at different scales. Students could *use models (e.g., physical, mathematical, computer models) to simulate the* **reaction and the reverse reaction in a chemical system** *at different scales*. HS-PS1-6 **Stability and Change** ● Changes and rates of change can be quantified and modeled over very short or very long periods of time. Students could *quantify* **change in the rates of chemical reactions** *over very short or very long periods of time*. HS-PS1-5
Additional Connections to Nature of Science	**Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ● Scientists often use hypotheses to develop and test theories and explanations. Students could describe *hypotheses* [that have] *tested theories about* **the balance between a reaction and the reverse reaction.** HS-PS1-6 **Science is a Human Endeavor** ● Technological advances have influenced the progress of science and science has influenced advances in technology. Students could gather information about *how science has influenced advances in* **mineral resources** *technology*. HS-ESS3-2

HS-PS1-5

Students who demonstrate understanding can:

HS-PS1-5. **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.** [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [*Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Disciplinary Core Ideas

PS1.B: Chemical Reactions

- 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.

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes the idea that as the kinetic energy of colliding particles increases and the number of collisions increases, the reaction rate increases.	
2	Evidence		
	a	Students identify and describe* evidence to construct the explanation, including:	
		i.	Evidence (e.g., from a table of data) of a pattern that increases in concentration (e.g., a change in one concentration while the other concentration is held constant) increase the reaction rate, and vice versa; and
		ii.	Evidence of a pattern that increases in temperature usually increase the reaction rate, and vice versa.
3	Reasoning		
	a	Students use and describe* the following chain of reasoning that integrates evidence, facts, and scientific principles to construct the explanation:	
		i.	Molecules that collide can break bonds and form new bonds, producing new molecules.
		ii.	The probability of bonds breaking in the collision depends on the kinetic energy of the collision being sufficient to break the bond, since bond breaking requires energy.
		iii.	Since temperature is a measure of average kinetic energy, a higher temperature means that molecular collisions will, on average, be more likely to break bonds and form new bonds.
		iv.	At a fixed concentration, molecules that are moving faster also collide more frequently, so molecules with higher kinetic energy are likely to collide more often.

		v.	A high concentration means that there are more molecules in a given volume and thus more particle collisions per unit of time at the same temperature.

HS-PS1-6

Students who demonstrate understanding can:

HS-PS1-6. **Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*** [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [*Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**PS1.B: Chemical Reactions** • 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. **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary)*	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students identify and describe* potential changes in a component of the given chemical reaction system that will increase the amounts of particular species at equilibrium. Students use evidence to describe* the relative quantities of a product before and after changes to a given chemical reaction system (e.g., concentration increases, decreases, or stays the same), and will explicitly use Le Chatelier's principle, including:	
		i.	How, at a molecular level, a stress involving a change to one component of an equilibrium system affects other components;
		ii.	That changing the concentration of one of the components of the equilibrium system will change the rate of the reaction (forward or backward) in which it is a reactant, until the forward and backward rates are again equal; and
		iii.	A description* of a system at equilibrium that includes the idea that both the forward and backward reactions are occurring at the same rate, resulting in a system that appears stable at the macroscopic level.
2	Describing criteria and constraints, including quantification when appropriate		
	a	Students describe* the prioritized criteria and constraints, and quantify each when appropriate. Examples of constraints to be considered are cost, energy required to produce a product, hazardous nature and chemical properties of reactants and products, and availability of resources.	

3	Evaluating potential solutions	
	a	Students systematically evaluate the proposed refinements to the design of the given chemical system. The potential refinements are evaluated by comparing the redesign to the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources).
4	Refining and/or optimizing the design solution	
	a	Students refine the given designed system by making tradeoffs that would optimize the designed system to increase the amount of product, and describe* the reasoning behind design decisions.

HS-ESS2-5

Students who demonstrate understanding can:

HS-ESS2-5. **Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations

Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Disciplinary Core Ideas

ESS2.C: The Roles of Water in Earth's Surface Processes

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.

Crosscutting Concepts

Structure and Function

- The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe* the phenomenon under investigation, which includes the following idea: a connection between the properties of water and its effects on Earth materials and surface processes.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including:	
		i.	Properties of water, including:
		a)	The heat capacity of water;
		b)	The density of water in its solid and liquid states; and
		c)	The polar nature of the water molecule due to its molecular structure.
		ii.	The effect of the properties of water on energy transfer that causes the patterns of temperature, the movement of air, and the movement and availability of water at Earth's surface.
		iii.	Mechanical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. Examples can include:
		a)	Stream transportation and deposition using a stream table, which can be used to infer the ability of water to transport and deposit materials;

		b) Erosion using variations in soil moisture content, which can be used to infer the ability of water to prevent or facilitate movement of Earth materials; and
		c) The expansion of water as it freezes, which can be used to infer the ability of water to break rocks into smaller pieces.
		iv. Chemical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. Examples can include:
		a) The solubility of different materials in water, which can be used to infer chemical weathering and recrystallization;
		b) The reaction of iron to rust in water, which can be used to infer the role of water in chemical weathering;
		c) Data illustrating that water lowers the melting temperature of most solids, which can be used to infer melt generation; and
		d) Data illustrating that water decreases the viscosity of melted rock, affecting the movement of magma and volcanic eruptions.
	b	In their investigation plan, students describe* how the data collected will be relevant to determining the effect of water on Earth materials and surface processes.
3	Planning for the Investigation	
	a	In their investigation plan, students include a means to indicate or measure the predicted effect of water on Earth's materials or surface processes. Examples include:
		i. The role of the heat capacity of water to affect the temperature, movement of air and movement of water at the Earth's surface;
		ii. The role of flowing water to pick up, move and deposit sediment;
		iii. The role of the polarity of water (through cohesion) to prevent or facilitate erosion;
		iv. The role of the changing density of water (depending on physical state) to facilitate the breakdown of rock;
		v. The role of the polarity of water in facilitating the dissolution of Earth materials;
		vi. Water as a component in chemical reactions that change Earth materials; and
		vii. The role of the polarity of water in changing the melting temperature and viscosity of rocks.
	b	In the plan, students state whether the investigation will be conducted individually or collaboratively.
4	Collecting the data	
	a	Students collect and record measurements or indications of the predicted effect of a property of water on Earth's materials or surface.
5	Refining the design	
	a	Students evaluate the accuracy and precision of the collected data.
	b	Students evaluate whether the data can be used to infer the effect of water on processes in the natural world.
	c	If necessary, students refine the plan to produce more accurate and precise data.

HS-ESS3-2

Students who demonstrate understanding can:

HS-ESS3-2. **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.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • 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).	**ESS3.A: Natural Resources** • All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. **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)*	- ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** • Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. • Analysis of costs and benefits is a critical aspect of decisions about technology. - ***Connections to Nature of Science*** **Science Addresses Questions About the Natural and Material World** • Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. • Science knowledge indicates what can happen in natural systems — not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. • Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

Observable features of the student performance by the end of the course:			
1	Supported claims		
	a	Students describe* the nature of the problem each design solution addresses.	
	b	Students identify the solution that has the most preferred cost-benefit ratios.	
2	Identifying scientific evidence		
	a	Students identify evidence for the design solutions, including:	
		i.	Societal needs for that energy or mineral resource;
		ii.	The cost of extracting or developing the energy reserve or mineral resource;
		iii.	The costs and benefits of the given design solutions; and
		iv.	The feasibility, costs, and benefits of recycling or reusing the mineral resource, if applicable.
3	Evaluation and critique		
	a	Students evaluate the given design solutions, including:	
		i.	The relative strengths of the given design solutions, based on associated economic, environmental, and geopolitical costs, risks, and benefits;
		ii.	The reliability and validity of the evidence used to evaluate the design solutions; and
		iii.	Constraints, including cost, safety, reliability, aesthetics, cultural effects environmental effects.
4	Reasoning/synthesis		
	a	Students use logical arguments based on their evaluation of the design solutions, costs and benefits, empirical evidence, and scientific ideas to support one design over the other(s) in their evaluation.	
	b	Students describe* that a decision on the "best" solution may change over time as engineers and scientists work to increase the benefits of design solutions while decreasing costs and risks.	

HS-ETS1-1

Students who demonstrate understanding can:

HS-ETS1-1. **Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.**

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Asking Questions and Defining Problems
Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions.

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

Crosscutting Concepts

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Connections to Engineering, Technology, and Applications of Science

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

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:

1	Identifying the problem to be solved		
	a	Students analyze a major global problem. In their analysis, students:	
		i.	Describe* the challenge with a rationale for why it is a major global challenge;
		ii.	Describe*, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and
		iii.	Document background research on the problem from two or more sources, including research journals.
2	Defining the process or system boundaries, and the components of the process or system		
	a	In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem.	
	b	In their analysis, students describe* societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy).	
3	Defining the criteria and constraints		
	a	Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem.	