CHEMISTRY

Energy from Chemical & Nuclear Processes

How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?



OpenSciEd

HIGH SCHOOL SCIENCE

TEACHER EDITION

How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?

Energy from Chemical & Nuclear Processes: Fuels

OpenSciEd Unit C.5



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UNIT OVERVIEW

How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?

This unit is anchored by the problem of continuing carbon dioxide emissions from transportation, despite the harm it causes established throughout the rest of the course. Students explore fifteen fuels used for transportation, ranging from "human power," to fossil fuels, biofuels, batteries, hydrogen, and uranium. In Lesson Set 1 (Lessons 1-8), students leverage data from physical and computational models to develop science ideas about how carbon-based fuels get energy from the breaking and forming of bonds, as energy transfers between particles and fields.

In Lessons 9-12 in Lesson Set 2, students figure out where energy comes from in fuels that are not carbon based. They also think more deeply about the energy implications of using different fuels. In Lesson Set 3 (Lessons 13-15) students are pushed to think at the transportation system level, and use engineering thinking to weigh science ideas from throughout the unit with information about larger social impact of fuels, including costs, availability, safety, and impacts on Earth systems.
Throughout the unit, students will do the following:

- Systematically use lenses of matter, energy, and forces to help explain the mechanisms behind different fuels providing energy to vehicles.
- Evaluate different possible future fuels using science ideas from the unit and new engineering tools that build on students' work in prior units.
- Support arguments and design decisions with data from a variety of sources.

Building Toward NGSS Performance Expectations

HS-ESS3-1:
Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ESS3-2:
Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

HS-ESS3-4:
Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

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.

HS-PS1-4:
Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

HS-PS1-8:
Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

HS-PS3-1:
Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2:
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

HS-PS3-5:
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.

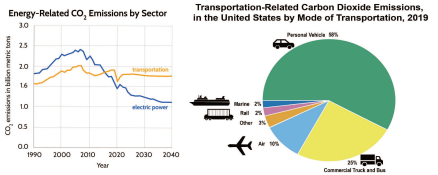
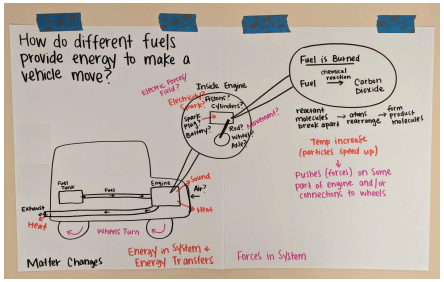
UNIT STORYLINE

Unit Question: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?

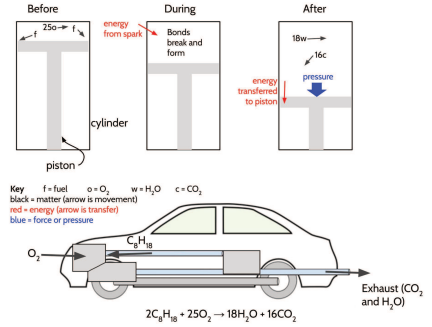
How students will engage with each of the phenomena

HANDS-ON/ LAB ACTIVITIES | VIDEOS OR IMAGES | DATA SETS | READINGS | COMPUTER INTERACTIVES

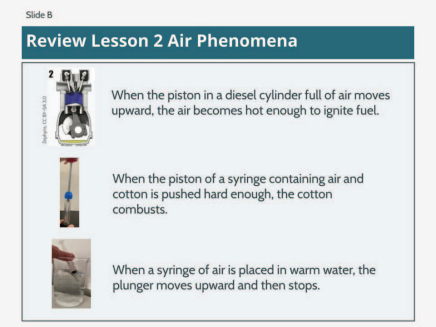
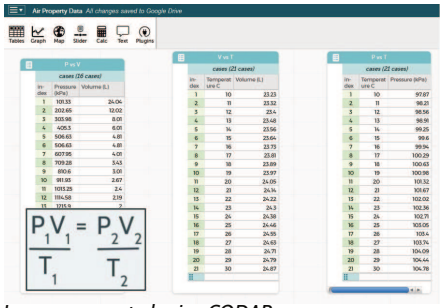
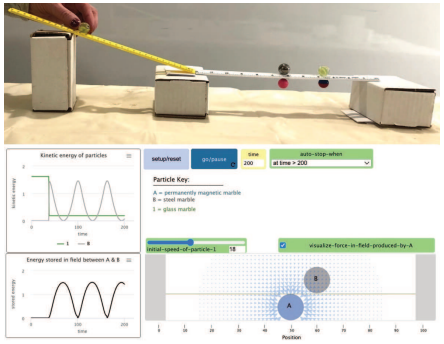
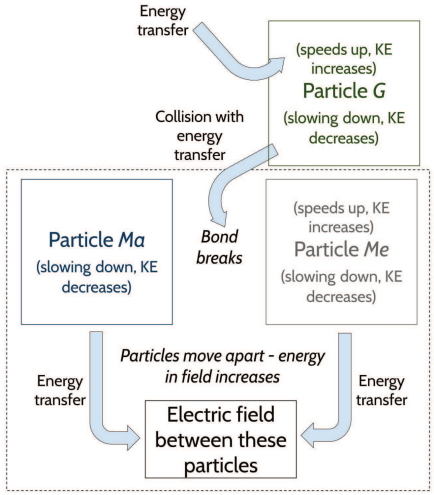
Lesson Set 1: How do carbon-based fuels release energy?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 3 days **What different fuels have we used, and do we currently use, for transportation?** Anchoring Phenomenon	 *Transportation is one of the leading sources of CO2 emissions. Different fuel sources are used to provide energy to make our vehicles move.*	We analyze data on sources of carbon emissions to think about which fuels we should consider for future vehicles. We figure out: • Most of the CO_2 emissions in the world come from transportation and electric power, and in transportation, cars and trucks are responsible for most of the emissions. • Different fuels are used to provide energy in the vehicles we use for transportation. • Different fuels contain different types of atoms, have different amounts of (or no) CO_2 emissions, have different energy released values, and come from different sources. • If we want to design a new generation of fuels or vehicles that do not contribute as much to climate change, there are other criteria we must consider as well.	

⇓ **Navigation to Next Lesson:** We have some gaps in our initial models related to what is happening inside the engine of a vehicle. We should inspect parts of the system more closely to see what is happening during combustion to clarify our models.

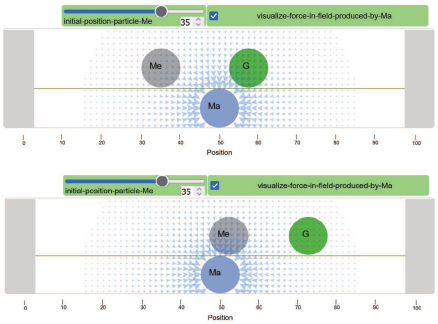
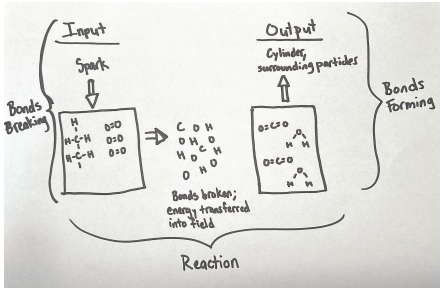
LESSON 2 Lesson Set 1 3 days **What is happening to the fuels inside the engine to make the vehicle move?** Investigation	 *Vehicles have structures that allow them to transfer energy from burning fuel in the engine to the wheels.*	We watch several demonstrations, examine different models, and revise models based on new information. We figure out: • The inputs of a combustion reaction are fuel and oxygen, and the outputs are carbon dioxide and water vapor. • The release of energy when fuel combusts in a vehicle engine results in forces applied to various parts of the vehicle, which cause the wheels to turn. • Diesel and biodiesel fuels provide more energy and less CO_2 emissions, but are not consumed as much as gasoline. • Engines that operate on diesel rather than gasoline work slightly differently.	

⇓ **Navigation to Next Lesson:** We have figured out that combustion reactions using either gasoline or diesel require some energy input to start, but the sources of this energy are different. We want to figure out where the energy input in diesel systems comes from.

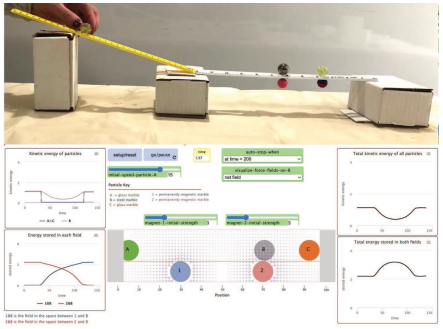
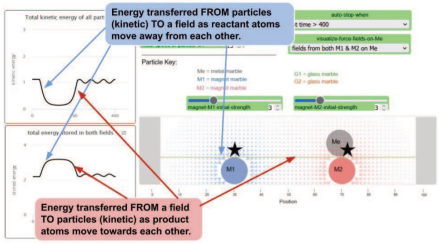
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 Lesson Set 1 1 day **How can diesel engines be working so differently from gasoline engines?** Investigation	 *For air-related phenomena from Lesson 2, there is a relationship between volume, temperature, and pressure.*	We examine relationships between the pressure, volume, and temperature of air in a closed system and use the Combined Gas Law to quantify those relationships. We figure out: • In a diesel engine, compressing air increases the air temperature above the ignition temperature of the fuel, causing the fuel to combust when it is injected. • We can determine how much pressure must be applied to the piston for the gas inside the diesel cylinder to reach the ignition temperature of a fuel using the Combined Gas Law. • As the air in the cylinder is compressed, its temperature increases because energy is transferred from the moving piston to the air molecules.	 *Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium.*
LESSON 4 Lesson Set 1 2 days **Why do we need to put energy into the system to start the reaction?** Investigation	 *Marbles and computer models can be used to illustrate interactions of molecules inside the cylinder system to explain why an energy input is required to break bonds in the reactants of combustion reactions.*	We use marbles and a computer model to examine what is happening as bonds break in a combustion reaction. We figure out: • Energy has to be transferred into the field between bonded atoms in order to overcome attractive forces and break them apart. • If too little energy is added to the system to break the bonds, they will wobble. This wobble is caused by energy moving into and out of the fields of the atoms in the reactant.	

⇓ **Navigation to Next Lesson:** We have figured out that there is a relationship between the pressure, volume, and temperature of a gas. When air in a diesel cylinder is compressed, it gets hot because energy is transferred to it from the moving piston. We want to figure out why an initial energy input is needed to start the combustion reactions in gasoline or diesel engines.

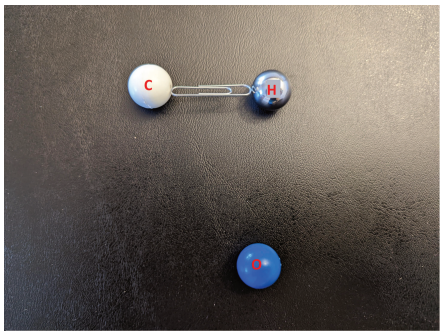
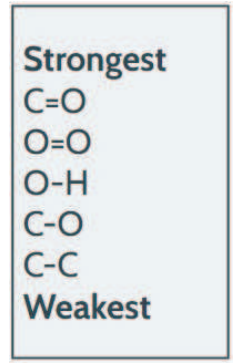
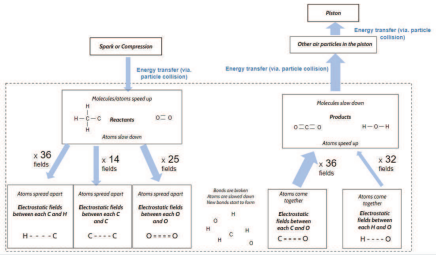
⇓ **Navigation to Next Lesson:** We have figured out why energy is needed to start combustion, but are unsure where the energy comes from in the reaction or why we continue to use carbon-based fuels even though they release carbon dioxide.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 5 Lesson Set 1 2 days **How and why is energy released when we burn carbon-based fuels?** Investigation	 *Marbles and a simulation help students model changes in matter and energy transfers as a result of force interactions when bonds form.*	We investigate bond formation using the magnet marbles and a simulation similar to the one from the prior lesson. We use the magnet marbles and simulation to observe the forces involved and energy changes that occur when a bond forms. We update our class consensus model to include energy transfers during bond breaking and formation, and read about the source of energy in carbon-based fuels. We complete an Electronic Exit Ticket to assess our understanding of changes in matter and energy when bonds form. We figure out: • As attracted particles move closer together, there is a decrease in the energy stored in the field and an increase in kinetic energy. • Forming a chemical bond results in an increase in particle-level kinetic energy. • Energy in all fuels can be traced back to the sun. These resources are important because they allow for the development of society and affect where and how people live. • There are arguments for and against fossil fuels and biofuels.	

⇓ **Navigation to Next Lesson:** We have a possible idea about both breaking and forming bonds together and have thought about energy production at a larger scale, but we are not certain that our model is complete or final and we have not tested it with many real fuels.

LESSON 6 Lesson Set 1 1 day **How does the amount of energy we put into the reaction system compare to the energy we get out?** Investigation	 *A computer model allows students to examine changes in matter, total kinetic energy, and total energy stored in fields over time as bonds of different strengths break and form.*	We use a physical model and a simulation to examine changes in kinetic energy as bonds break and form. We figure out: • The total energy (energy stored in electric fields and kinetic energy of particles) is conserved in a chemical reaction. • In our simulation, net energy is transferred from the field if the bonds formed are stronger than the bonds broken. • In our simulation, net energy is transferred to the field if the bonds broken are stronger than the bonds formed. • A minimum amount of energy must be transferred to the field to break a bond and start the reaction. This is called the activation energy.	 *Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.*

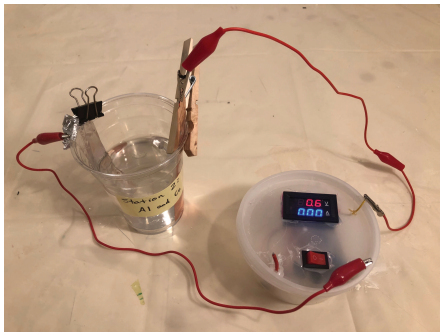
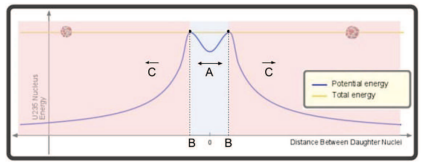
⇓ **Navigation to Next Lesson:** Now that we can explain why we get energy out of the system from combusting fuels, we want to see if we can apply these ideas to figure out why fuels are different.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 7 Lesson Set 1 2 days **How can fuels release different amounts of energy when they all have bonds breaking and forming?** Investigation	 *Electronegativity differences and magnet marbles can be used to predict and model different bond strengths.*	We revisit everything we have figured out about how energy is involved in bond breaking and formation to make sense of how the types of atoms being bonded affect the bond energy. We then use these different bond energies to create a visual and mathematical representation of the energy transferred into fields to break the reactant bonds in methane combustion and the energy released when forming its products. We end our class revisiting the DQB to see what questions we can answer. We figure out: • The number of bonds broken and formed cannot fully explain the energy transferred out of a combustion reaction. • High-electronegativity elements tend to form stronger bonds than low-electronegativity elements. • More energy must be transferred to the field to break a strong bond compared to a weaker bond and more energy is transferred from the field when a strong bond is formed.	
LESSON 8 Lesson Set 1 3 days **How does our understanding of carbon-based fuels inform our decision-making?** Putting Pieces Together	 *A chemical reaction between potassium chloride and water decreases in temperature, and a chemical reaction between calcium chloride and water increases in temperature.*	We explain and model why carbon-based fuels provide energy. We think about the impacts of carbon dioxide emissions and return to our Progress Trackers. We check in on our DQB and complete a mid-unit assessment on hot and cold packs. We figure out: • All fuels release energy when they are burned because the total bond energy of the products is greater than the total bond energy of the reactants. We can use this to explain the behavior of different fuels. • The amount of carbon dioxide produced by fuel combustion is related to the number of carbon atoms in the fuel. All carbon-based fuels emit large amounts of carbon dioxide when burned. • In cold packs, energy transfers in and out of fields result in a temperature decrease. In hot packs, energy transfers in and out of fields result in a temperature increase. This applies even when dissolution is the main process.	

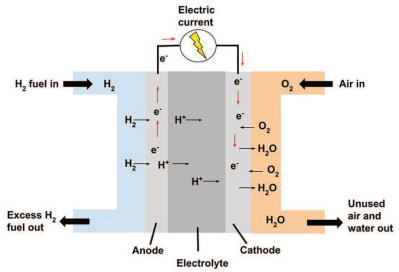
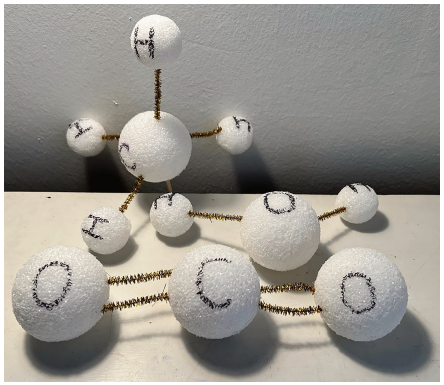
⇓ **Navigation to Next Lesson:** We figured out that different bond strengths result in different amounts of energy being transferred into and out of the field and used this to predict energy transfer. We are ready to put all the pieces from the unit together.

⇓ **Navigation to Next Lesson:** We still have a lot of fuels that we have not investigated, and we are interested in whether they would be viable alternatives to carbon-based fuels.

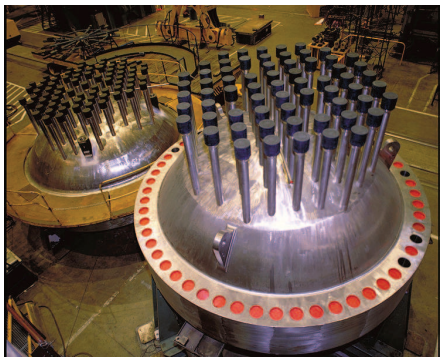
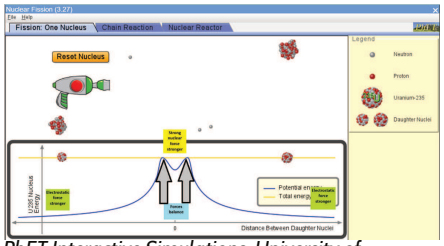
Lesson Set 2: How do fuels that are not carbon based release energy?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 9 Lesson Set 2 2 days **Where is the energy coming from (and what are some trade-offs) when we use batteries to power vehicles?** Investigation	 *Electric vehicles have some significant advantages, as well as disadvantages, compared to gasoline-powered vehicles. Some of these issues can be addressed by improving battery technology, so we investigate how batteries work.*	We learn about the benefits and drawbacks of using electric vehicles powered by batteries. We analyze images of batteries and conduct investigations using different metal electrodes. We analyze data on the current produced by different electrolytes. We develop a battery design proposal that would provide the highest energy output rate. We figure out: • Batteries and EVs have a lot of benefits but also some drawbacks in the short term relating to the environment and accessibility. • Differences in the types of solutions and metals used in batteries can affect the energy they can provide. • Combining metals with a larger difference in electronegativity in a battery can transfer more energy. • Batteries provide a vehicle energy as electrons move through wires and ions move through solution, transferring energy from fields to particles.	 *PhET Interactive Simulations, University of Colorado Boulder*

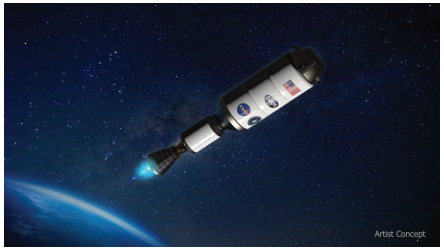
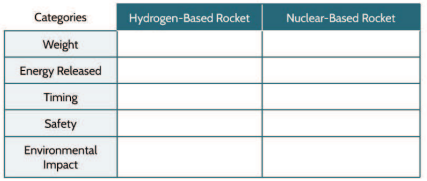
⇓ **Navigation to Next Lesson:** We still need to explain how hydrogen would be able to power a vehicle.

LESSON 10 Lesson Set 2 1 day **How can we use hydrogen as a fuel and what are the impacts?** Investigation	 *Hydrogen fuel cells have similar components to batteries and generate electricity by reacting hydrogen fuel with oxygen.*	We learn about how fuel cells generate electricity from hydrogen fuel. We determine that most hydrogen is produced from methane with the emission of carbon dioxide. We identify the locations of hydrogen refueling and battery recharging stations. We figure out: • Hydrogen fuel cells are similar to batteries in that they directly produce electricity and similar to engines in that they have inputs (hydrogen and oxygen) and outputs (water). • Most hydrogen is produced from fossil fuels in a process that also emits carbon dioxide. • Greenhouse gasses persist in the atmosphere and wobble (vibrate) a lot when they absorb infrared radiation emitted by Earth. • Some special criteria and constraints must be considered with hydrogen fuel cells for transportation (not enough refueling stations, greenhouse gas emissions during hydrogen production).	

⇓ **Navigation to Next Lesson:** We still need to explain how energy could be output from a single atom, uranium.

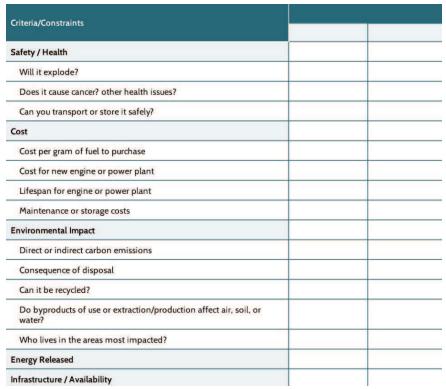
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 11 Lesson Set 2 3 days **Where is the energy coming from when we use uranium as a fuel?** Investigation, Problematizing	 *Uranium provides much more energy than the chemical reactions we have examined so far even though there is nothing to react, as it just consists of one type of atom.*	We examine how nuclear processes are similar and different from chemical reactions using M-E-F thinking. We jigsaw readings that describe different concerns with using uranium as fuel and added to our Progress Trackers. We figure out: • In nuclear fission, neutrons and protons are conserved, but atoms can change into different elements as large nuclei split. • We would expect protons to repel due to electrostatic forces, but when there are the right ratios of protons and neutrons in a nucleus, the strong nuclear force is able to hold them together. This force only works on short ranges. • When protons and neutrons get just too far apart for the strong nuclear force to take hold, protons repel strongly due to the electrostatic force and energy transfers from electric fields to the particles, causing a drastic increase in temperature. • Various constraints around size, safety, cost, and environmental concerns have limited the use of uranium as a fuel, particularly in transportation.	 *PhET Interactive Simulations, University of Colorado Boulder*

⇓ **Navigation to Next Lesson:** We have figured out how different fuels provide energy. We can start to think more systematically about their application to transportation problems.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 12 Lesson Set 2 1 day **How can our knowledge of fuel trade-offs support our evaluation of future rocket fuels?** Putting Pieces Together	 *The increased abundance of space missions is leading to a greater environmental impact.*	We observe a video showing the process of how astronauts will reach Mars. We develop a list of criteria and constraints that engineers and scientists need to explore when choosing a rocket fuel. We read an article comparing the differences between chemical and nuclear rockets. We then work in groups to rank our criteria and constraints and compare each type of rocket against them. Finally, we individually argue for which, or neither, fuel should be used in future space missions. We figure out: • More space flights using carbon-based fuels is harming the atmosphere. • Uranium has a much higher energy released than hydrogen fuels. • Hydrogen-fueled rockets release no harmful products, while nuclear rockets' exhaust is radioactive. • Nuclear-powered rockets will lead to less travel time, which means astronauts will be exposed to less cosmic radiation than if traveling in chemical-fueled rockets.	 Categories / Hydrogen-Based Rocket / Nuclear-Based Rocket Weight Energy Released Timing Safety Environmental Impact

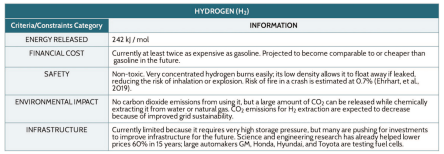
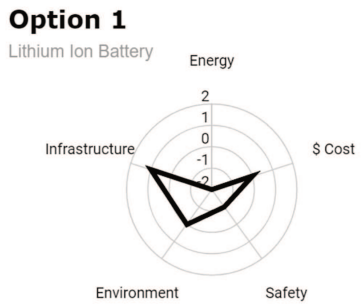
⇓ **Navigation to Next Lesson:** We have examined an engineering problem around a specific type of transportation and have what we need to think about the whole transportation system.

Lesson Set 3: How can we use what we have learned to improve our transportation system?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 13 Lesson Set 3 2 days **Why do we use some fuels rather than others?** Problematizing, Investigation	 *It is difficult to evaluate new transportation solutions based only on environmental impacts because the effects are complex and there are both benefits and costs for each solution.*	We create a draft decision matrix and use it to evaluate two transportation solutions on the basis of environmental impact. We realize that our initial criteria and constraints are too complex and should be broken into subcategories. We update our consensus decision matrix to include subcategories for other criteria and constraints. We figure out: • Evaluating the benefits of different transportation solutions requires comparison against clear criteria and constraints. Each transportation solution has trade-offs that must be considered before implementation. • It is helpful to break large, broad criteria into smaller, more specific parts to better evaluate possible solutions.	

Criteria/Constraints		
Safety / Health		
Will it explode?		
Does it cause cancer? other health issues?		
Can you transport or store it safely?		
Cost		
Cost per gram of fuel to purchase		
Cost for new engine or power plant		
Lifespan for engine or power plant		
Maintenance or storage costs		
Environmental Impact		
Direct or indirect carbon emissions		
Consequence of disposal		
Can it be recycled?		
Do byproducts of use or extraction/production affect air, soil, or water?		
Who lives in the areas most impacted?		
Energy Released		
Infrastructure / Availability		

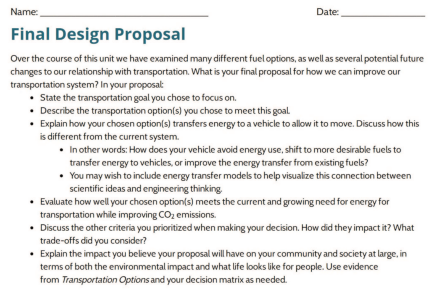
⇓ **Navigation to Next Lesson:** We want to test our consensus decision matrix by using it to evaluate competing transportation alternatives.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 14 Lesson Set 3 3 days **How do we decide on the best transportation options for our future?** Investigation	 *There is a lot to consider when designing for future transportation systems. Using quantitative tools can help us organize and interpret the data to support our decision-making process.*	We use data from various sources to evaluate transportation options and develop arguments for which ones are best to use in the future. We figure out: • Radar charts can be used to help visualize complex data sets. This allows for better comparison and ability to find patterns in data. • Quantifying data into positive and negative values can help us to clearly compare the costs and benefits of using certain transportation options over others. • Making decisions is a multistep process and is influenced by our individual priorities.	

HYDROGEN (H_2)	
Criteria/Constraints Category	INFORMATION
ENERGY RELEASED	242 kJ / mol
FINANCIAL COST	Currently at least twice as expensive as gasoline. Projected to become comparable to or cheaper than gasoline in the future.
SAFETY	Non-toxic. Very concentrated hydrogen burns easily; its low density allows it to float away if leaked, reducing the risk of inhalation or explosion. Risk of fire in a crash is estimated at 0.7% (Ehrhart, et al., 2019).
ENVIRONMENTAL IMPACT	No carbon dioxide emissions from using it, but a large amount of CO_2 can be released while chemically extracting it from water or natural gas. CO_2 emissions for H_2 extraction are expected to decrease because of improved grid sustainability.
INFRASTRUCTURE	Currently limited because it requires very high storage pressure, but many are pushing for investments to improve infrastructure for the future. Science and engineering research has already helped lower prices 60% in 15 years; large automakers GM, Honda, Hyundai, and Toyota are testing fuel cells.

⇓ **Navigation to Next Lesson:** We are wondering how to wrap up all we have learned and include the helpful critiques we have received. We decide to finalize our arguments using feedback we received from our peers.

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

LESSON 15
Lesson Set 3
 	
2 days
 	
How can we make transportation decisions to benefit our communities and Earth?
 	
Putting Pieces Together
	
	
	There are many ways that we could improve our transportation systems; what we ultimately decide to do is the result of prioritized criteria, our values, social contexts, environmental impacts, and available engineering solutions.
		We use our prioritized criteria, arguments from Lesson 14, and feedback on our arguments to propose a final transportation design solution. We reflect on our progress in this unit and throughout the chemistry course. We figure out:
		• We can combine our chemistry knowledge, engineering decisions, and prioritized criteria to create a final transportation design proposal.
		• We can use chemistry and engineering to design transportation solutions that provide the needed energy for transportation while reducing negative environmental impacts.
			
			Name: _____ Date: _____
			Final Design Proposal
			Over the course of this unit we have examined many different fuel options, as well as several potential future changes to our relationship with transportation. What is your final proposal for how we can improve our transportation system? In your proposal:
			• State the transportation goal you chose to focus on.
			• Describe the transportation option(s) you chose to meet this goal.
			• Explain how your chosen option(s) transfers energy to a vehicle to allow it to move. Discuss how this is different from the current system.
			  • In other words: How does your vehicle avoid energy use, shift to more desirable fuels to transfer energy to vehicles, or improve the energy transfer from existing fuels?
			  • You may wish to include energy transfer models to help visualize this connection between scientific ideas and engineering thinking.
			• Evaluate how well your chosen option(s) meets the current and growing need for energy for transportation while improving CO_2 emissions.
			• Discuss the other criteria you prioritized when making your decision. How did they impact it? What trade-offs did you consider?
			• Explain the impact you believe your proposal will have on your community and society at large, in terms of both the environmental impact and what life looks like for people. Use evidence from *Transportation Options* and your decision matrix as needed.

⇓ **Navigation to Next Lesson:** This is the last lesson of the unit.

LESSONS 1-15

31 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements For Science Investigations

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

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

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

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

Please follow these lab safety recommendations for any science investigation:

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


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

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

This unit is the fifth and final unit in the OpenSciEd High School Chemistry course sequence. In the previous unit of OpenSciEd HS Chemistry, students developed ideas around reversible reactions, acids and bases, and dynamic equilibrium. This unit is designed to build on student's ideas about electrostatic forces, matter, and bond energy, with an emphasis on modeling how the relative positions of particles predicts the transfer of energy. This unit also contributes to core ideas for Earth and Space Science and Engineering, Technology, and Society, especially how science and engineering can change the impacts of human activity on Earth's systems.

While HS-PS1-4 is addressed in this unit alone in the OpenSciEd course sequence, many of the Performance Expectations (PEs) in this unit are shared across other Chemistry or Physics units:

- **HS-PS1-8** is shared with *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* and *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*, where ideas of fusion and radioactive decay are developed.
- **HS-PS3-1** is shared with *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, and *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.
- **HS-PS3-2** is shared with *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, *Electricity Unit*, and *Meteors Unit*.
- **HS-PS3-5** is shared with *Electrostatics Unit* and *Electricity Unit*.
- **HS-ESS3-1** is shared with *Polar Ice Unit*.
- **HS-ESS3-2** is shared with *Electricity Unit*.
- **HS-ESS3-4** and **HS-ETS1-1** are shared with *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

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

For the anchoring phenomenon, students explore fifteen fuels used in US transportation, including human power, gasoline, biofuels, uranium, batteries, kerosene jet fuel, and a range of other carbon-based fuels. They notice that different fuels have different amounts of CO_2 emitted for the amount of energy produced. They realize they need to figure out what's going on inside an engine to figure out where "energy released" might be coming from, and in future lessons they model a personal vehicle, the combustion reaction, and the particles (matter), fields, and energy transfers that occur in a reaction.

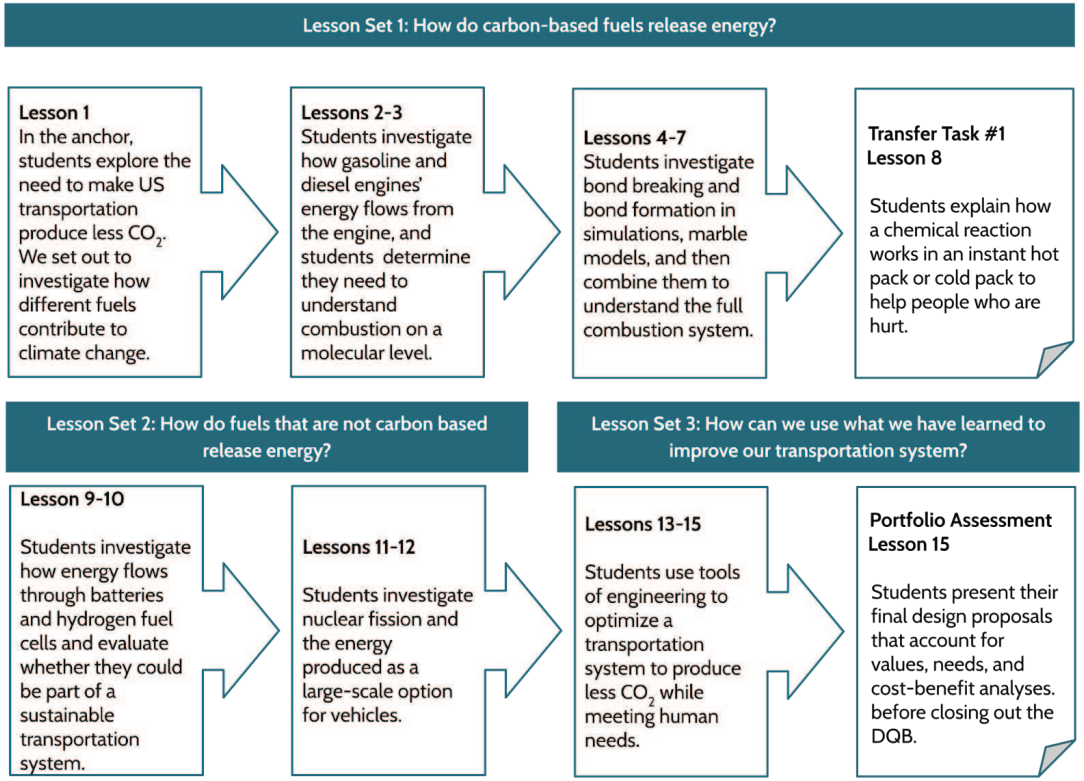
Student interest in mitigating the effects of climate change is high, and students have a range of interests in fuels: learning to drive at approximately the same time as chemistry class, the costs of fueling their own car, and the ubiquity of reliable transportation needs. Interestingly, teachers have reported that the inclusion of diesel and gas engines has been shown to garner interest from typically less chemistry-identified demographics students (especially rural and BIPOC male students interested in cars).

The anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. The phenomenon of transportation systems and the question "How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?" were chosen for the following reasons:

- Very high interest to students across location (urban/suburban/rural), highest average score overall, and very high across all self-identified races and ethnicities. Interestingly, rural students' interest in this phenomenon was slightly lower than suburban and urban students', but rural students still showed strong interest in fuels' composition and social issues related to how we choose to get around.
- Teachers saw high relevance to students learning to drive and facing fluctuating costs at the gas pump.
- Explaining the structure and combustion of fuels very closely addresses the selected pieces of DCIs in this bundle at a high school level.
- Students can investigate the micro-level of bonds breaking and forming.
- Major social considerations around the future of transportation invite science-based answers that drive the unit, such as, "How will we use fuels in the future, given our planet and economic needs?"

How is the unit structured?

The unit is organized to answer the question, "How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?" Students work through this question in three lesson sets. Lesson Set 1 (Lessons 1-8) focuses on developing science ideas about the **breaking and formation of bonds** as a function of **fields, energy, and matter** via interactive physical models (rulers & marbles) and online simulations of the same. Throughout Lesson Set 1 (Lessons 1-8), the emphasis is on carbon-based fuels as students answer the question, "How do carbon-based fuels release energy?" Students develop science ideas about bond-breaking and -making as they investigate fossil fuel combustion. Lessons 9-12 in Lesson Set 2 investigate other types of fuels for transportation systems that are not carbon-based, including models of **battery energy circulation and nuclear fission** as students answer the question, "How do fuels that are not carbon based release energy?" Lesson Set 3 (Lessons 13-15) requires **engineering thinking** throughout as students weigh science ideas from throughout the unit with information about larger social impact of fuels, **including costs, availability, safety, and impacts on earth systems.** Students answer the question, "How can we use what we have learned to improve our transportation system?" A system of transfer tasks allows students to demonstrate their understanding and receive feedback in Lessons 8, 12, and 15. Students are given feedback throughout Lesson Set 3 via a STAMP Protocol, and students reflect on this feedback using a portfolio.



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

This unit is designed to support students in developing an understanding of how energy transfers between particles and the electric fields between them, bonds, and thermal energy flow in a chemical reaction. As students investigate and design for energy output in combustion systems and other fuel sources, the unit intentionally increases the complexity of each practice, DCI, and crosscutting concept.

Constructing explanations and designing solutions is **intentionally developed** across the unit, beginning in Lesson 2 as students are supported to apply reasoning to link evidence and claims as they figure out chemical reactions that drive the majority of our high-CO_2-emitting vehicles. Students have the opportunity to optimize their design ideas across the entire unit, building on design and explanation in lessons 5, 7, and assessed in a transfer task in Lesson 8. Then in Lessons 9, 11, 14, and 15, students' explanations and designs get more complex as they increasingly account for values, ethics, student-generated sources of evidence, and tradeoffs as they use energy and matter to explain how transportation systems rely on a variety of chemical reactions, nuclear processes, and battery-fueled ions and bring the patterns of mathematics into their design work.

Analyzing and interpreting data is **intentionally developed** across the unit, beginning in Lesson Set 1 as students encounter graphs and quantitative information about how energy is moving in systems where chemical reactions are taking place. To add complexity to this practice, students must encounter and incorporate new data into their models in Lessons 10 & 11 as they work to refine their systems of transportation to optimize them based on values, cost, and energy flow.

Engaging in argument from evidence is **intentionally developed** across the unit, beginning in Lesson 5 as students use the data they have collected to evaluate the arguments in favor of and against fossil fuels and biofuels as combustion-based fuels, which is practice for the more intense work they will do in Lesson Set 3 to optimize a system of transportation with the avoid-shift-improve engineering framework. Students build more complex arguments in lessons 12, 13, and 14 as they reason with cause and effect about how to optimize an engineered system, receive and incorporate feedback from peers (Lesson 14), and are assessed via a portfolio.

Cause & effect is **intentionally developed** across the unit. Cause and effect is a lens for thinking about chemical reactions throughout this unit and becomes more complex as students add more components to the chemistry model (Lesson Sets 1 & 2) and on to the social systems model (Lesson Set 3). In Lesson Set 1, students must **explain** mechanisms of large scale changes like a combustion engine while reasoning about molecular-level causes that become more complicated as different fuels and engines are reasoned with. Cause and effect is most developed in Lesson Set 3 (Lessons 10, 11, 12, 11, and 15) as students work on **designing a system to cause a desired effect**, using mathematical and graphical representations in later lessons to add to their arguments. Students are assessed on cause and effect in a portfolio-style assessment across these lessons.

Energy and matter is **intentionally developed** across the unit. Energy and matter forms an integral lens for thinking about how a chemical reaction is the result of the movement of energy from fields into the system and back into fields. In Lessons 1, 2, 4, 5, and 6, students track changes in energy and flows in a vehicle and then down to the molecular scale to understand the ways that energy is moving. In Lessons 1 and 5-8, students take up the idea that energy is conserved. Students model how, in a closed system, energy is conserved in Lessons 5 and 7, building complexity as students **analyze and interpret data** related to bond breaking, bond formation, and the combined effect of both breaking and remaking bonds which is assessed in a transfer task in Lesson 8. To add further complexity, in Lesson 11, students must **evaluate the impact of new data** about nuclear processes where atoms are not conserved, but matter and energy are. Finally, the Lesson 15 transfer task addresses how changes in energy can be described in terms of energy and matter flows as they explain the ways that their proposed system could work.

Connections to Middle School OpenSciEd Units

This unit builds **science and engineering practices (SEPs)** that students should have previously developed *in the context of physical science standards related to chemistry* in middle school units *OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*. Students' use of **Argument from Evidence** increases its sophistication from middle school as students "become more adept at arguing and critiquing ... [and] encouraged to recognize the criteria used to judge claims for new knowledge," (NRC, 2012, p.74). In the former unit, students use this practice as they organize and use evidence to support claims that temperature changes are due to the movement of heat rather than cold between samples of matter (MS Argument 7.3). In the latter unit, students intentionally develop this practice as they incrementally assemble a multiple-step argument, supporting each step with evidence, for an explanation for what happens to the matter of the bath bomb in water (MS Argument 7.1, 7.3). As students collect new data, information, or evidence, they construct arguments for their explanations of the various phenomena in the unit (MS Argument 7.1, 7.2, 7.3). These middle school units do not require weighing new evidence or student-generated data against an argument or respectful scientific critique.

Students' use of **Analyzing and Interpreting Data** increases in its sophistication from middle school as students "add additional techniques for displaying and analyzing data" (NRC, 2012, p.63). In the Middle School *Cup Design Unit*, students intentionally develop this practice as they work with averages, issues of accuracy, and modify data collection methods (MS Analyze and interpret data 4.2, 4.4, 4.5, 4.6, 4.7). In the Middle School *Bath Bombs Unit*, student intentionally develop this practice as they collect data to determine the substances in the bath bomb that cause the gas, record data from flammability and density tests of gases and use a property data table to determine what gas could be produced, and argue for what additional data they need to analyze (MS Analyze and interpret data 4.4, 4.7). In the Middle School *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*, students intentionally develop this practice as they define an optimal operational range for a flameless heater that best meets criteria for success (MS Analyze and interpret data 4.8). These data analyses are limited to tables at the MS level.

Students' use of **Constructing Explanations and Designing Solutions** increases its sophistication from middle school as students "undertake more complex engineering design projects related to major local, national, or global issues. Increased emphasis should be placed on researching the nature of the given problems, on reviewing others' proposed solutions, on weighing the strengths and weaknesses of various alternatives, and on discerning possibly unanticipated effects" (NRC, 2012, p.71). In the Middle School *Cup Design Unit*, students intentionally develop this practice as they leverage scientific ideas to design, construct, test, and optimize an object that is designed to slow energy transfer (SEP 6.4, 6.6, 6.7, 6.8). In the Middle School *Bath Bombs Unit*, students intentionally develop this practice as they explain a number of chemical reaction phenomena such as bath bombs and crumbling marble on the Taj Mahal. In the Middle School *Homemade Heater Unit*, students use this practice as they design, construct, and test a flameless heater system that can be used to heat food in an emergency by prioritizing criteria, making tradeoffs, testing, revising, and re-testing (SEP 6.6, 6.7, 6.8). These MS units do not require weighing the strengths and weaknesses of various alternatives systematically.

This unit builds upon **Crosscutting Concepts (CCCs)** that students should have previously developed or used *in the context of physical science standards related to chemistry* in Middle School *Cup Design Unit*, *Homemade Heater Unit* and *Magnets Unit*. Students' use of **Matter and Energy** increases its sophistication from middle school as students learn to understand how energy moves among systems and the ways that energy and matter flow continuously. This includes nuclear energy. (NGSS Appendix G, p.9). In the Middle School *OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* students intentionally develop this crosscutting concept as they trace matter through physical changes and within/across systems, drawing on the idea that matter is conserved (CCC 5.1, 5.3, 5.4). In the Middle School *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)* students intentionally develop this crosscutting concept as they consider the transfer of energy between parts of the system they are designing and the impact of the matter—how the substances that are part of the chemical reaction system are changed and how amounts of matter in the chemical reaction system and the food system impact design decisions (CCC 5.2, 5.4). In the Middle School *Magnets Unit*, students use the lens of matter and energy as they use the ideas of fields to understand energy transfers.

Students' use of **Cause and Effect** increases its sophistication from middle school as students apply their understandings of cause and effect to larger systems (NGSS Appendix G, 2013, p.6). In the Middle School *OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)* students intentionally develop this crosscutting concept as they use cause and effect relationships to predict how we hear sound from a speaker, what will happen when a coil of wire is connected to a battery, and the changing direction of forces and shape of a magnetic field (MS Cause and effect 2.1, 2.2, 2.3). This 8th grade unit limits cause and effect to one object and does not account for larger societal causes and effects.

This unit builds toward these performance expectations:

HS-PS1-4 Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
HS-PS1-8† Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, ~~fusion, and radioactive decay~~.
HS-PS3-1† Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2† Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
HS-PS3-5† 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.
HS-ESS3-1* Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS3-2† Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*
HS-ESS3-4* Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
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.

*This performance expectation is developed across multiple units.
†This performance expectation is developed across multiple courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
Constructing Explanations and Designing Solutions This unit **intentionally develops** students' engagement in these practice elements: • 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. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. • Design, evaluate, and/or refine a solution to a complex real-world problem, based on	**PS1.A: Structure and Properties of Matter** • Stable forms of matter are those in which the electric and magnetic field energy is minimized. 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. (HS-PS1-4) **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. (HS-PS1-4), (HS-PS1-5) **PS1.C Nuclear Processes** • Nuclear processes, including ~~fusion,~~ fission, ~~and radioactive decays of unstable nuclei,~~ involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8) **PS3.A: Definitions of Energy**	**Cause & Effect** This unit **intentionally develops** students' engagement in these crosscutting concept elements: • 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. • Changes in systems may have various causes that may not have equal effects. **Energy and Matter** This unit **intentionally develops** students' engagement in these crosscutting concept elements: • The total amount of energy and matter in closed systems is conserved. • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. • Energy cannot be created or destroyed—it only moves between one place and another place,

scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. **Engaging in Argument from Evidence** This unit **intentionally develops** students' engagement in these practice elements: • Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues • Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. • Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions. • Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. **Analyzing and Interpreting Data** This unit **intentionally develops** students' engagement in these practice elements: • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. • Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. The following practices are also **key to the sensemaking** in this unit: • **Developing and Using Models**	• ~~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-PS3-1, HS-PS3-2)~~ • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3) • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). ~~This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.~~ (HS-PS3-2) **PS3.B: Conservation of Energy & 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.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) **ESS3.A Natural Resources** • Resource availability has guided the development of human society. (HS-ESS3-1) • All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2) **ESS3.B Natural Hazards** • ~~Natural hazards and other~~ geologic events have shaped the course of human history; [they] have significantly	between objects and/or fields, or between systems. • In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. The following crosscutting concepts are also **key to the sensemaking** in this unit: • **Patterns** • **Scale, Proportion, and Quantity** • **Structure and Function**

	altered the sizes of human populations and have driven human migrations. (HS-ESS3-1) **ESS3.C Human Impacts on Earth Systems** • Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4) **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. (HS-ETS1-1) • Humanity faces major global challenges today, such as the need for ~~supplies of clean water and food or for~~ energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) **ETS1.B Developing Possible Solutions** • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3), (secondary to HS-ESS3-2), (secondary to HS-ESS3-4) **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 (tradeoffs) may be needed. (HS-ETS1-2), (secondary to HS-PS1-6), (secondary to HS-PS2-3)	

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

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
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)	The basic laws that are consistently applied to the universe in this unit are the presence and function of intermolecular forces, especially positive-negative attraction and repulsion in Lessons 4-7. The vast scale of difference of nuclear process is also addressed in Lessons 11 and 12.

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-ESS3-2) • Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. (HS-ESS3-2)	The ethical issues addressed in this unit center around the question, "who's responsible?" for different types of emissions, pollution, and for remediating our reliance on fossil fuels. Lessons 1 and 13-15 involve the values of different actors in emissions and US vehicle use. The ethical issues intersect with scientific issues, especially in Lesson Set 3, where chemistry knowledge is leveraged alongside social science knowledge to help students propose a solution to fossil fuel use. Students also must rely on the social and cultural contexts of fossil fuel reliance, gasoline/diesel infrastructures to address the issue of fuel use.

Connections to Engineering, Technology and Applications of Science (ETS)	
Which elements of ETS are developed in the unit?	How are they developed?
Influence of Science, Engineering, and Technology on a Society and the Natural World: • Modern civilization depends on major technological systems. (HS-ESS3-1) • 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, HS-ESS3-4) • Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS3-2) • New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1)	Historical uses of fuels for transportation and changes in devices used for transportation (e.g., battery design) are examined by students in Lessons 1 and 9. Changes in battery design, development of hydrogen fuel cells, and use of nuclear fuel in transportation are examined from both costs and benefits perspectives in Lesson Set 2. Consideration of costs and risks associated with fuels used in transportation designs including resource extraction, refinement, and end products after use from both the scientific and engineering perspectives is explored in Lesson Set 3. In Lessons 13-15, costs and benefits around use of specific fuels are analyzed to help inform decision making.

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

This unit uses and builds upon **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in OpenSciEd Middle School or another middle school science program.

- MS-PS1.A: Structure and Properties of Matter (*OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*, *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*, *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)*, *OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*, *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*)
  - 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. (MS-PS1-1)
  - Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. (MS-PS1-2), (MS-PS1-3)
  - Gases and liquids are made of molecules or inert atoms that are moving around. (MS-PS1-4)
- MS-PS1.B: Chemical Reactions (*OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*, *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)*, *OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*)
  - Some chemical reactions release energy, others store energy. (MS-PS1-6)
  - Substances react in chemically characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. (MS-PS1-2), (MS-PS1-3), (MS-PS1-5)
  - The total number of each type of atom is conserved, and thus the mass does not change. (MS-PS1-5)
- MS-PS3.A: Definitions of Energy (*OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*, *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*, *OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)*).
  - Motion energy is properly called kinetic energy; it is proportional to the mass of the moving objects and grows with the square of its speed. (MS-PS3-1)

    - A system of objects may also contain stored (potential) energy, depending on their relative positions. (MS-PS3-2)
    - The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. (p. 47 of Atlas)
- MS-PS3.B: Conservation of Energy and Energy Transfer (*OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*)
    - When the motion energy of an object changes, there is inevitably some other change in energy at the same time. (MS-PS3-5)
    - The amount of energy transfer needed to change the temperature of a matter sample of a given amount depends on the nature of the matter, the size of the sample, and the environment. (MS-PS3-4)
- MS-PS3.C: Relationship Between Energy and Forces (material: df])
    - When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. (MS-PS3-2)
- MS-ETS1.A: Defining and Delimiting an Engineering Problem (*OpenSciEd Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit)*, *OpenSciEd Unit 6.5: Where do natural hazards happen and how do we prepare for them?(Tsunami Unit)*)
    - The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. (MS-ETS1-1, secondary to MS-PS3-3)
- MS-ETS1.B: Developing Possible Solutions (*OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*, *OpenSciEd Unit 6.5: Where do natural hazards happen and how do we prepare for them?(Tsunami Unit)*, *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*, *OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)*, *OpenSciEd Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)*)
    - A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. (MS-ETS1-4, secondary to MS-PS3-3)
    - There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. (MS-ETS1-2, MS-ETS1-3)
    - Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)
    - Models of all kinds are important for testing solutions. (MS-ETS1-4)
- MS-ESS3.A: Natural Resources (*OpenSciEd Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)*)
    - 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. (MS-ESS3-1)
- MS-ESS3.C: Human Impacts on Earth Systems (*OpenSciEd Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit)*, *OpenSciEd Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)*)
    - 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. (MS-ESS3-3), (MS-ESS3-4)

This unit uses and builds upon **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in OpenSciEd High School Biology and Chemistry.

- HS-PS1.B: Chemical Reactions (*OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*)
    - 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. (HS-PS1-4)
- HS-PS2.B: Types of Interactions (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*)
    - 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. (HS-PS2-6), (secondary to HS-PS1-1), (secondary to HS-PS1-3)
- HS-PS3.A: Definitions of Energy (*OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*)
    - 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-PS3-1, HS-PS3-2)
        - **Note:** This element was fully built in *Polar Ice Unit* and *Electrostatics Unit*, and is further assessed in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*. Although it is used in several lessons in this unit, it is crossed out because it is never explicitly assessed.

    - At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)
    - These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)
- HS-PS3.B: Conservation of Energy & Energy Transfer (*OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*)
    - 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)
        - **Note:** This element was fully built in *Polar Ice Unit* and is further assessed in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*. Although it is used in several lessons in this unit, it is crossed out because it is never explicitly assessed.
    - 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)
        - **Note:** This element will be developed in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, which focuses on energy efficiency. Although this idea is introduced in general terms in this unit, as students think about fuel mileage in Lesson 8, it is not developed sufficiently to be claimed.
- HS-PS3.C Relationship Between Energy and Forces (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*)
    - When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)
- ESS3.A Natural Resources (*OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*)
    - Resource availability has guided the development of human society. (HS-ESS3-1)
    - All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2)
- ESS3.B Natural Hazards (*OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*)
    - Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations. (HS-ESS3-1)
- ESS3.C Human Impacts on Earth Systems (*OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*)
    - Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4)
- ETS1.A Defining and Delimiting Engineering Problems (*OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*)
    - 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. (HS-ETS1-1)
    - Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1
- ETS1.B Developing Possible Solutions (*OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)*, *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*)
    - 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) (HS-ESS3-2, HS-ESS3-4)

This unit begins or continues the development of **disciplinary core ideas (DCIs)** and other science ideas that students will utilize and continue building in subsequent units in the OpenSciEd Chemistry and Physics courses:

- HS-PS1.A Structure and Properties of Matter (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*)
    - At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)
    - Stable forms of matter are those in which the electric and magnetic field energy is minimized. 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. (HS-PS1-4)
- HS-PS1.C Nuclear Processes (*OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*, *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*)
    - Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8)

- HS-PS3.A Definitions of Energy (*OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*, *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*)
    - 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-PS3-1),(HS-PS3-2)
    - At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)
    - These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)
- HS-PS3.B Conservation of Energy and Energy Transfer (*OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*)
    - 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),(HS-PS3-4)
    - 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)
- HS-ESS3.A Natural Resources (*OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*)
    - 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)
- HS-ETS1.A Defining and Delimiting Engineering Problems (*OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*)
    - 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. (HS-ETS1-1)
    - Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)
- HS-ETS1.B Developing Possible Solutions (*OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*)
    - 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) (HS-ESS3-2), (HS-ESS3-4)
- HS-ETS1.C (*OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*)
    - 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 (tradeoffs) may be needed. (HS-ETS1-2) (secondary to HS-PS1-6) (secondary to HS-PS2-3)

The M-E-F (matter-energy-forces) poster was built by students starting in *Polar Ice Unit* and used throughout the course. It is also used in this unit and in OpenSciEd High School Physics as students continue exploring the relationships between matter, energy, and forces. Students previously understood that matter is made up of particles (atoms and molecules) and that energy is a quantitative property, related to particle motion, that can be transferred through various mechanisms. In this unit, they will expand on this thinking to understand how energy can be transferred in and out of fields, generated by charged matter, through forces.

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

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

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

What are some common ideas that students might have?

Students will come into the unit with many ideas about transportation systems that are derived from previous everyday experiences, intuitive understandings of the way the world works, and the conversations they have had with parents, friends, and family members.

Some relevant ideas (both accurate and inaccurate) that students may come into the unit with include the following:

- **Gasoline, diesel and engine function:** Teenagers may have experience with cars and engines; many teens are learning to use a gasoline-powered car, and age 18 or 19 is when students can seek a CDL license to drive a large commercial truck in many states. Thus they often are more knowledgeable about transportation systems and their laws and requirements than adults. Every attempt should be made to honor their experiences with different transportation systems.
- **Battery-operated vehicles:** As battery-powered vehicles and related policy decisions proliferate, students will have opinions about what they think should be encouraged or allowed.
- **Transportation systems:** Teenagers in urban areas often derive freedom from the use of metro transit systems, on which they can get to activities for reduced cost and for increased freedom. They are often aware of the inequities in the system or ways that their systems do not serve youth adequately. For example, some teens might not feel

safe in their neighborhoods' transit systems, and this is a topic that can be brought up in Lesson Set 3. Similarly, students from rural areas may recognize that their areas are not well-served by public transit.

- **Particle nature of matter:** Matter is made of particles in motion that interact through collisions. (C.1)
- **Subatomic particles:** Atoms have positive nuclei and mobile negative electrons, as well as neutrons. (C.2 and C.3)
- **Energy in fields:** Energy can be transferred into, stored in, and transferred out of electric fields. Students might assume that energy is released in reactions because bonds break (i.e., the energy "leaks out"). This noncanonical idea is common. The OpenSciEd High School Biology course was designed to minimize development of this idea with its treatment of photosynthesis, but listen for ideas about energy "coming out of bonds." If you hear these ideas past Lesson 5 or 6, encourage students to continue to think about how it takes an application of force (and an energy input) from their hands to break a "bonded" magnet pair. (C.2)
- **Nature of bonds:** A bond between atoms forms when they are attracted to and share pairs of electrons in their outer shell. Electronegativity plays an important role in bonding. (C.3)
- **Balancing and predicting reactions:** Matter conservation can be used to help predict the amount(s) of substance(s) produced by chemical reactions. More energy transfer is required to break strong bonds than weak ones. (C.3)
- **Engineering:** Prioritizing criteria and constraints and breaking a problem up into pieces help us solve problems. (C.4)

It is valuable to think of noncanonical ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, but it also improves science learning across the board. Following these ideas, and building explicitly from these ideas to draw connections, is a productive pedagogical tool that will help students construct new, more accurate conceptual models of the structure and properties of matter.

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

This is the final unit of the High School Chemistry Course in the OpenSciEd Scope and Sequence. We have assumed a traditional sequencing of OpenSciEd Biology, then Chemistry, then Physics. Given this placement, the following modifications would be needed if students do not take OpenSciEd Biology first, or if the Chemistry Course is taught out of order. These include the following adjustments:

- Because the OpenSciEd HS Chemistry course sequence was designed with this unit last, the unit's design assumed that students have had significant practice with a number of chemistry procedures and topics, such as stoichiometry, unit conversions, measurement, and models of matter, forces, and energy that pertain to matter at the subatomic scale on up. If taught out of sequence, students may experience incoherence and phenomenon fatigue due the amount of supplementation that may be required, and the unit may take double or triple the length of time to teach. For this reason, we recommend teaching other chemistry units before this one.
- If taught as part of an **AP Chemistry** course, be prepared to provide students with additional support around thermodynamic equations and enthalpy that are not treated in depth. You may also wish to build toward ideas of Gibbs free energy and entropy to more fully explain which chemical processes occur and why.
- Students who take OpenSciEd HS Chemistry **before biology** are not anticipated to experience significant incoherence for this unit.
- Students who take OpenSciEd HS Chemistry **after physics** will have a stronger basis for the understanding of energy released and energy absorbed into a field. Thus, lessons 4-7 may go faster. You may decide on different terminology for "energy stored in a field" if it makes sense given students' experience with physics.

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

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

- Focus on Lesson Set 1 to emphasize combustion reactions and bond formation. If combustion reaction principles are not required, Lessons 4-7 can be skipped.
- Lesson 2: BTB can be combined with alcohol in the watch glass and the color changes to yellow when ethanol burns. This alternative saves time.
- Lesson 3 was added to meet the needs of many schools to address gas laws and to answer more detailed student questions about the differences between gasoline and diesel. The data portion that leads to the introduction of the Combined Gas Law may be omitted if these ideas were introduced elsewhere or are not required in your context.
- Focus or bypass Lesson 11 if students do not have questions about nuclear energy or if nuclear energy is not in your chemistry scope and sequence.
- Lesson 12 may be skipped if students are not interested in nuclear-powered rockets or if students have had enough practice with nuclear energy.

Remember that teaching storylines out of order will require extra attention and preparation on the part of teachers because a number of slides and questions will be made irrelevant by changes to the sequence.

To extend or enhance the unit, consider the following:

- Lesson 1: If you are not in the United States, you may replace the data on slide E with data from your own country. Likely starting points for a search include governmental databases, local university programs that focus on climate or environmental science, or sites like OurWorldInData.
- Lesson 1: Extend the discussion or allow students to lead the Scientists Circle.
- Lesson 1: Encourage students to gather data from folks who have lived in your school community at least 40 years to learn what transportation used to be like. Including your area's history of transportation from a historical, economic, or human geography can deepen the relevance of the unit.

- Lessons 2-15: There are a total of 20 extension or additional activities that can support or deepen students' experiences. These can take up to 1 class period or as little as 10 minutes; see callouts in each lesson describing the particular extensions or alternate activities.
- Lesson 3: This lesson includes particular guidance for introducing students to the ideal gas law, if required in your context.
- Lesson 8: There are alternate assessments provided for students who need additional opportunities to achieve the LLPEs. See the Lesson 8 Assessment Key for pointers about how to support students in more deeply engaging with the topics.
- Lesson 13-15: consider a student-choice project to take some small action to use science and engineering to improve the school or local community. Potential mini-unit questions could include engaging a local audience with the research they have uncovered into their transportation alternative. Your area may have a transportation council that meets to discuss improvements to roads or infrastructure; perhaps students could attend or present at those meetings. Orienting students toward action is one way to reduce climate anxiety and to demonstrate firsthand how science and engineering can be locally compelling and useful.

What mathematics concepts will students engage with in the unit?

This unit requires students to use unit conversions, both along with and separate from stoichiometric thinking.

This unit does not introduce new mathematical ideas in a science context. It instead draws on previously-developed mathematical thinking from *Polar Ice Unit* (unit conversions), *Space Survival Unit* (balancing chemical equations), and *Oysters Unit* (stoichiometry). Thus these standards are not so much prerequisites, as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below.

Talk with the math teacher(s) to identify the strategies students are familiar with for conducting unit conversions, particularly if you did not use *Polar Ice Unit*.

Category	Code	Domain and Heading	Standard	Lesson
Number and Quantity	CCSS.MATH.CONTENT.HS.N-Q.1	**Quantities:** Reason quantitatively and use units to solve problems.	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.~~	2, 7, 8

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

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

Many of these strategies are highlighted in the teacher guides in sidebar or in-line callout boxes with the headings of:

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

The example callouts below highlight how additional guidance is provided to attend to a variety of student needs in instruction.

Supporting emerging multilingual learners. Students may benefit from a brief word sort on cards to help clarify the relationships they are mapping back to the piston system. These words include: push, movement, heat, and pressure. Have students identify where each of these things occurs within the cylinder system, then add onto that by having them identify how each of these words explains one part of the M-E-F poster. Another option is to have students use the words in a sentence and use 3 different colored highlighters to show M-E-F thinking.

Supporting Universal Design for Learning: Allowing for student choice of the three fuel data cards they will examine as well as how to sort their cards, helps support *engagement*. Individual choice and autonomy are leveraged in this activity. Students will compare their sorting ideas in their small groups, which also supports *engagement* by fostering collaboration and community.

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

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the "Where we are going" and "Where we are not going" sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**PS1.A: Structures and Properties of Matter, PS1.B: Chemical Reactions**, **PS2.B: Types of Interactions**, **ESS1.A: The Universe and Its Stars**, **ESS2.A: Earth Materials and Systems**, **ESS2.C: The Roles of Water in Earth's Surface Processes**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and Performance Expectations bundle for this unit:

For information about the anchoring phenomenon and different fuels

- US Energy Information Administration. EIA.gov. Oil and petroleum products explained: Use of oil basics. https://www.eia.gov/energyexplained/oil-and-petroleum-products/use-of-oil.php Accessed 6 March 2023.
- Alternative Fuels Data Center: Alternative Fuels and Advanced Vehicles. (2024). Energy.gov. https://afdc.energy.gov/fuels/
- Environmental Protection Agency. EPA.gov. Comparison: Your car vs. an EV. https://www.epa.gov/greenvehicles/comparison-your-car-vs-electric-vehicle

For information about transportation systems and the shift to greener fuels:

- Keep Cool newsletter podcast: pod.link/1613789172
- On optimizing the use of gas-powered cars: US Department of Energy. Fueleconomy.gov. Personalize. https://www.fueleconomy.gov/feg/Find.do?action=customize&return=https%3A%2F%2Fwww.fueleconomy.gov%2Ffeg%2FFind.do%3Faction%3Dsbs%26id%3D46970%26%23tab1

For support with emotions and youth during the climate crisis

- GenDread Climate Crisis emotional support network: https://gendread.substack.com/

For energy stored in fields

- NRC. (2013). *A framework for K-12 science education: Chapter 9*. https://nap.nationalacademies.org/read/13165/chapter/9#120
- Fortus, D., Kubsch, M., Bielik, T., Krajcik, J., Lehavi, Y., Neumann, K., Nordine, J., Optiz, S., & Touitou, I. (2019). Systems, transfer, and fields: Evaluating a new approach to energy instruction. *Journal of Research in Science Teaching, 56*, 1341-1361. https://onlinelibrary.wiley.com/doi/epdf/10.1002/tea.21556

For nuclear energy (fission is the only component addressed in this unit)

- US Energy Information Administration: https://www.eia.gov/energyexplained/nuclear/nuclear-power-plants.php#:~:text=Nuclear%20power%20comes%20from%20nuclear%20fission&text=Nuclear%20fission%20occurs%20when%20a,can%20initiate%20a%20chain%20reaction.
- Ritchie, H., Rosado, P., & Roser, M. (2024, March 20). Nuclear Energy. Our World in Data. https://ourworldindata.org/nuclear-energy
- *Simulation Mapping* in Lesson 11 explains and provides more resources on how a field model of energy is applied to nuclear fission in this unit.

Vehicles and transportation

- Stay current with the news on infrastructure and EV technology. Most car manufacturers are redesigning their infrastructures to shift toward more electric and hybrid-powered vehicles, and the EV industry is expected to shift quickly over the coming decades. Consider asking a local EV owner to show their vehicle and answer questions to support students in reconciling any misconceptions about how EVs work.

How do I support students' emotional needs?

In this unit, students explore the challenges associated with the mitigation of climate change. This may raise issues concerning climate crisis trauma:

- Trauma associated with direct impacts of climate change, such as displacement due to fire, flood, or other disaster.
- Strong beliefs about equity and justice issues connected with a future in the climate crisis.
- Coping mechanisms such as anger or feigned disbelief or rejection of the climate crisis.

Before beginning this unit, make sure to reach out to the counselor at your school for student-specific support and strategies that might be needed in regard to the students in your classroom. Consider asking the counselor to join you in the classroom for the DQB build in **Lesson 1** to gauge the extent to which students might need emotional support. Also consider planning follow-up check-ins with the counselor in regard to any students who may need additional emotional support as they work with the unit's design problem of carbon emissions that cause climate change and pollution.

Educate yourself about how climate concerns are impacting youth and causing distress as they worry for their futures and safety here: https://gendread.substack.com/

Plan ahead with ways to scaffold justice-oriented teaching. Consider the following websites:

- Resource: Learning for Justice: Critical Practices: https://www.learningforjustice.org/frameworks/critical-practices
- Facing History & Ourselves: https://www.facinghistory.org/resource-library?search=colonialism

Be aware that students who are struggling with difficult emotions in class may demonstrate a variety of behaviors, including but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, and change in body language or intonation. If you notice a student might be struggling, share what you are observing and ask if they need some help.

What is the Learning in Places Nature-Culture Relations framework?

This unit is informed by the Learning in Places complex socio-ecological systems framework. This framework involves sensemaking across five dimensions (species, kinds & behaviors; relationships; places, lands & waters, thinking across scales, and ethical deliberation and decision-making) under an umbrella of power and historicity. These dimensions include making sense of both human and other-than-human values, needs, and behaviors across multiple temporal and spatial scales. The framework guides learners towards designing actions or making decisions for making change in adaptive and resilient ways. Students use these dimensions implicitly throughout the unit, but particularly in Lesson Set 3 as they consider how the transportation system could be improved and what implications this might have. You may choose to make this framework explicit to students for whom the engineering-focused prompts are not making sense to make it clear that they are simply engaging in structured, ethical decision-making.

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

For more about socio-ecological deliberation and decision-making, please visit http://learninginplaces.org/. Learning in Places Collaborative. (2022). Framework: Complex Socio-Ecological Systems. Bothell, Seattle, WA & Evanston, Il: Learning in Places.

Guidance for Developing Your Personal Glossaries

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

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

The definitions we co-construct and encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they are trying to figure out.

Lesson	Definitions we co-construct	Definitions we encounter

L1	carbon-based fuels	emissions, reactions*
L2	combustion reaction, pressure	
L3		combined gas law
L4		bond*
L5		
L6	activation energy	
L7	exothermic reaction, endothermic reaction, bond energy	electronegativity*
L8		lattice energy, energy of hydration
L9		anode, cathode, voltage, voltmeter
L10		
L11	isotopes, nuclear fission	neutron*, chain reaction, nuclear waste, nuclear reactor, strong nuclear force, control rod
L12		
L13		
L14		radar charts
L15		tradeoff*

* co-constructed in a previous OpenSciEd High School Chemistry Unit

HOME COMMUNICATION

Dear Guardian,

Your child's high school chemistry class is starting a unit called *How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?*, as part of the OpenSciEd high school science curriculum. This unit develops science ideas around the source of the energy when different chemical fuels (like gasoline or biodiesel), batteries, or nuclear fuel are used and helps students use engineering thinking to address issues of natural resources and the environment. Throughout the unit, students will draw on their own experiences and everyday understandings to help them figure out complex science ideas as they use data from our world and from their own investigations.

(Revise this paragraph if not using this unit as a capstone to the OpenSciEd High School Chemistry course.) Throughout the course, students have figured out how atmospheric carbon dioxide, released through human use of fossil fuels, causes various problems in Earth systems, including climate change. Transportation is responsible for the majority of carbon dioxide emissions in the United States and therefore an important piece of the puzzle in fighting climate change. Students will consider the costs and benefits of a wide range of fuels, as well as efforts to reduce fuel use, as they make their own decisions about what our transportation system should look like. See this link for more information about sustainable transportation: https://www.energy.gov/eere/sustainable-transportation-and-fuels. You can also learn more about climate change generally at https://theconversation.com/five-climate-change-science-misconceptions-debunked-122570.

Your child may be one of 84% of Americans ages 16 to 25 who are at least moderately worried about climate change (as are the majority of American adults). You can learn more about *climate anxiety* and ways to support your child at https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-20220613 2761.

If your child or someone close to your child has been heavily impacted by climate change, please contact me at __(contact information here)__, if you are comfortable doing so. You can also contact the school counselor at __(contact information here)__. By knowing about these experiences in advance we can be sensitive to students' needs and provide support for students who may experience strong emotions during this unit.

Having conversations about science in our world:

- Encourage your child's curiosity through talking about their own noticings and wonderings.
- Acknowledge any emotions around climate change.
- Ask your child to explain where the energy is coming from in different fuels and discuss their ideas about their relative costs and benefits.

Emphasize that we can take action on climate change. Have honest conversations with your child about what they, personally, can do, while taking into consideration the needs of those who are most affected by climate change and other issues with the current transportation system or would be impacted by changes in the system.

Helping your student make sense of their learning:

- There is no need to teach your child vocabulary before the unit because words often have multiple meanings, and are often easier to remember once students have some experience with them.
- Encourage your child to expand and clarify their own thinking by asking your child for examples, saying more about their ideas, and repeating what your child said back to them.
- Ask how they might have arrived at a particular conclusion.
- Ask your child to recall what other students have said in class, and what parts of their ideas your child agreed or disagreed with.
- Rephrase what your child is saying to check your own understanding. For example, say, "If I hear you right, you are telling me that..."

Best,
(Your name or signature here)

Querido guardián,

La clase de química de la escuela secundaria de su hijo está comenzando una unidad llamada *¿Cómo puede la química ayudarnos a evaluar combustibles y opciones de transporte para beneficiar a la Tierra y nuestras comunidades?*, como parte del plan de estudios de ciencias de la escuela secundaria OpenSciEd. Esta unidad desarrolla ideas científicas sobre la fuente de energía cuando se utilizan diferentes combustibles químicos (como gasolina o biodiesel), baterías o combustible nuclear y ayuda a los estudiantes a utilizar el pensamiento de ingeniería para abordar preguntas sobre recursos naturales y el medio ambiente. A lo largo de la unidad, los estudiantes aprovecharán sus propias experiencias y conocimientos cotidianos para ayudarlos a descubrir ideas científicas complejas mientras utilizan datos de nuestro mundo y de sus propias investigaciones.

(Revise este párrafo si no utiliza esta unidad como proyecto final del curso de Química de la escuela secundaria OpenSciEd). A lo largo del curso, los estudiantes han descubierto cómo el dióxido de carbono atmosférico, liberado por el uso humano de combustibles fósiles, causa diversos problemas en los sistemas de la Tierra, incluido el cambio climático. El transporte es responsable de la mayoría de las emisiones de dióxido de carbono en Estados Unidos y, por tanto, una pieza importante del rompecabezas en la lucha contra el cambio climático. Los estudiantes considerarán los costos y beneficios de una amplia gama de combustibles, así como los esfuerzos para reducir el uso de combustible, mientras toman sus propias decisiones sobre cómo debería ser nuestro sistema de transporte. Consulte este enlace para obtener más información sobre el transporte sostenible: https://www.energy.gov/eere/sustainable-transportation-and-fuels. También puede obtener más información sobre el cambio climático en general en https://theconversation.com/five-climate-change-science-misconceptions-debunked-122570.

Es posible que su hijo forme parte del 84% de los estadounidenses de entre 16 y 25 años que están al menos moderadamente preocupados por el cambio climático (al igual que la mayoría de los adultos estadounidenses). Puede aprender más sobre la *ansiedad climática* y formas de apoyar a su hijo en https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-202206132761.

Si su hijo o alguien cercano a él se ha visto gravemente afectado por el cambio climático, comuníquese conmigo al __(información de contacto aquí)__, si se siente cómodo haciéndolo. También puede comunicarse con el consejero escolar al __(información de contacto aquí)__. Al conocer estas experiencias de antemano, podemos ser sensibles a las necesidades de los estudiantes y brindarles apoyo a los estudiantes que puedan experimentar emociones fuertes durante esta unidad.

Tener conversaciones sobre la ciencia en nuestro mundo:

- Fomente la curiosidad de su hijo hablándole sobre sus propias observaciones y preguntas.
- Reconozca cualquier emoción en torno al cambio climático.
- Pídale a su hijo que le explique de dónde proviene la energía en los diferentes combustibles y analice sus ideas sobre sus costos y beneficios relativos.

Enfatice que podemos tomar medidas sobre el cambio climático. Tenga conversaciones honestas con su hijo sobre lo que él, personalmente, puede hacer, teniendo en cuenta las necesidades de aquellos que se ven más afectados por el cambio climático y otros problemas con el sistema de transporte actual o que se verían afectados por los cambios en el sistema.

Ayudar a su estudiante a hacer sentido de su aprendizaje:

- No es necesario enseñarle vocabulario a su hijo antes de la unidad porque las palabras suelen tener múltiples significados y suelen ser más fáciles de recordar una vez que los estudiantes tienen algo de experiencia con ellas.
- Anime a su hijo a ampliar y aclarar su propio pensamiento pidiéndole ejemplos, diciéndole más sobre sus ideas y repitiendo lo que le dijo.
- Pregúntele cómo pudo haber llegado a una conclusión particular.
- Pídale a su hijo que recuerde lo que otros estudiantes han dicho en clase y con qué partes de sus ideas estuvo de acuerdo o en desacuerdo.
- Reformule lo que su hijo dice para comprobar su propia comprensión. Por ejemplo, diga: "Si te escuché bien, me estás diciendo que..."

Atentamente,
(Su nombre o firma aquí)

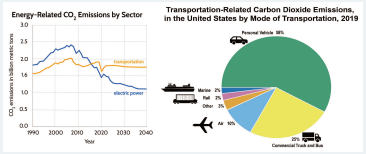
LESSON 1: What different fuels have we used, and do we currently use, for transportation?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

3 days



We analyze data of carbon dioxide emissions from transportation and electric power, and of different fuels used by different types of vehicles. We develop models to explain how fuels provide energy to make vehicles move. We identify criteria that might make one fuel more desirable to use than another. We develop a Driving Question Board and ideas for investigations and data we need to answer our questions.

NEXT LESSON *We will examine diagrams that show how gasoline provides energy to a vehicle. We will analyze the changes that occur using our M-E-F poster and test our ideas. We will analyze data to identify more optimal fuels. We will develop a model to summarize our ideas, then examine how diesel engines work and compare them to gasoline engines.*

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

1.A Develop a model based on evidence (chemical formula, energy released, and carbon dioxide emission) to illustrate the matter change, energy transfer, and force interaction relationships between the components of the system to explain how a fuel (matter) is used to provide energy in a vehicle system to make it move. (SEP: 2.3; DCI: PS3.A.2, PS3.A.4; CCC: 5.3)

1.B Ask questions that arise from and seek additional information about: patterns in data related to fuel use in transportation; attempts to explain how matter (fuel) and energy transfer in a vehicle to produce movement; and attempts to identify criteria and constraints to inform design solutions for next-generation vehicle fuel use. (SEP: 1.1, 1.8; DCI: PS3.A.2, ESS3.C.2; CCC: 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Most of the CO_2 emissions in the world come from transportation and power, and in transportation, cars and trucks are responsible for most of the emissions.
- Different fuels are used to provide energy in the vehicles we use for transportation.
- Different fuels contain different types of atoms, have different amounts of (or no) CO_2 emissions, have different energy released values, and come from different sources.
- If we want to design a new generation of fuels or vehicles that do not contribute as much to climate change, there are other criteria we must consider as well.

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		**NAVIGATE** Lead a whole-class discussion to identify global problems and related solutions previously studied in the course.	A	
2	6 min		**CONSIDER CAUSES OF CO2 EMISSION CHANGES** Have students turn and talk with a partner to analyze a graph of past CO_2 emissions data.	B-C	
3	6 min		**ANALYZE PER-CAPITA EMISSIONS DATA** Lead a class discussion to brainstorm technologies that use fuel for transportation. Have the class analyze data on the amount of carbon emissions by type of transportation.	D-E	
4	21 min		**EXPLORE DIFFERENT TYPES OF FUELS** Show a fuel data card to the whole class. Organize students in small groups to work with the fuel data cards.	F-I	Fuel Data Cards
5	8 min		**DEVELOP INITIAL MODELS** Have students individually develop an initial model to explain how a fuel is used to provide energy to make a vehicle move.	J-K	*Initial Fuel Model*, Fuel Data Cards
					End of day 1
6	3 min		**REFLECT ON COMMUNITY AGREEMENTS** Display the Community Agreements. Have students individually choose one focal agreement to work on for the rest of class and share it with a partner.	L-M	Community Agreements
7	7 min		**COMPARE INITIAL MODELS USING M-E-F THINKING** Have students work with a partner to use M-E-F thinking to talk about different perspectives in their initial models.	N	*Initial Fuel Model*, colored pencils, M-E-F poster
8	15 min		**DEVELOP AN INITIAL CLASS CONSENSUS MODEL** Gather the class in a Scientists Circle to develop an initial consensus model.	O-R	*Initial Fuel Model*, chart paper, colored markers
9	3 min		**ASK SCIENCE-RELATED QUESTIONS ABOUT THE PHENOMENA** Have students record questions about the science principles behind fuel use in vehicles.	S	3x3 sticky notes, colored markers
10	15 min		**BRAINSTORM CRITERIA AND CONSTRAINTS TO EVALUATE FUTURE FUELS AND GENERATE QUESTIONS** Prompt students to have partner discussions around criteria that might make one fuel more desirable than another and constraints that fuels must meet. Give students time to generate questions.	T-V	*Initial Fuel Model*, Fuel Data Cards, 3x3 sticky notes, colored markers, chart paper markers, "Criteria and Constraints for Evaluating Fuels for Transportation" poster

Part	Duration		Summary	Slide	Materials
11	2 min		**NAVIGATE** Introduce the home learning to students.	W	
					End of day 2
12	3 min		**NAVIGATE** Have students turn and talk with a partner to share their home learning findings.	X	"Criteria and Constraints for Evaluating Fuels for Transportation" poster, chart paper markers
13	21 min		**BUILD THE DRIVING QUESTION BOARD** Have students review and revise any questions they may have. Organize the class into a Scientists Circle to begin building the DQB.	Y-AA	3x3 sticky notes, colored markers, DQB
14	6 min		**IDENTIFY SCIENCE AND ENGINEERING QUESTIONS** Help students distinguish between science and engineering questions on the Driving Question Board.	BB	two colors of small sticky dots (preferably green and blue), DQB
15	12 min		**BRAINSTORM AND SHARE IDEAS FOR INVESTIGATIONS AND DATA NEEDED** Have students brainstorm and share ideas for investigations and sources of data needed to answer our DQB questions.	CC-DD	chart paper, chart paper markers
16	3 min		**REFLECT ON TACKLING GLOBAL PROBLEMS AND SOLUTIONS** Have students complete an exit ticket to reflect on how we feel about exploring additional solutions to global problems related to climate change.	EE	
					End of day 3

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Initial Fuel Model* • Fuel Data Cards • 3x3 sticky notes • colored markers • two colors of small sticky dots (preferably green and blue)	• Fuel Data Cards • colored pencils • 3x3 sticky notes • colored markers	• Community Agreements • M-E-F poster • chart paper • colored markers • chart paper markers • "Criteria and Constraints for Evaluating Fuels for Transportation" poster • DQB

Materials preparation (20 minutes)

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

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

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

Sort seven decks of 15 Fuel Data Cards each. These should be printed in color and saved for future use. They are typically included in purchased kits. Two optional cards--wood and coal--are included. You may choose to use these cards if steam-operated devices are a particular area of interest for your students, but specific questions about the use of wood and coal as transportation fuels are not addressed in the unit as written.

On day 2, display the M-E-F poster that the class began co-constructing in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and finished building in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. If you do not have this poster, you may reconstruct it using the reference from *Electrostatics Unit* Lesson 3.

Make sure the Community Agreements for your class are in a place visible for all students on day 2.

Create a poster on a piece of chart paper titled, "Criteria and Constraints for Evaluating Fuels for Transportation" to use on day 2.

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS3.A.2 Definitions of Energy:** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- **PS3.A.4 Definitions of Energy:** These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles ~~or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.~~
- **ESS3.C.2 Human Impacts on Earth Systems:** Scientists and engineers can make major contributions by developing technologies that produce less pollution ~~and waste and that preclude ecosystem degradation~~.

Crossout explanation: Students previously built ideas of energy stored in fields in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. They may leverage them here, but are more likely to focus force thinking on the more concrete forces themselves. After field thinking throughout Lesson Set 1, they will apply it to manifestations of energy in Lesson 9. All this energy thinking builds on prior work from *Electrostatics Unit*. Students will more explicitly consider pollution, waste, and ecosystem degradation in Lessons 9 and 10. They also considered these Earth science ideas in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* and *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

Students begin to consider different sources of carbon dioxide emissions and identify that the transportation sector is responsible for most of the current emissions. They consider the impacts of various types of transportation on those emissions.

Students individually *develop models* to explain how a fuel is used to provide energy to make a vehicle move (SEP: 2.3; DCI: PS3.A.2; CCC: 5.3). Students meet with a partner to consider how *matter changes, energy transfer*, and forces act on the vehicle and fuel to make the vehicle move (CCC: 5.3). They use this thinking to *revise their initial models* (SEP: 2.3). The class works together to *develop an initial consensus model* (SEP: 2.3; CCC: 5.3). The practice of modeling and crosscutting concepts of matter and energy have both been developed throughout the course.

Students start to *develop questions* about the scientific areas of the phenomena pertaining to *matter and energy flows* (SEP: 1.1; CCC: 5.2). Students are also prompted to develop questions to help frame the engineering design problems (SEP: 1.8; DCI: ESS3.C.2). As part of home learning, students are prompted to ask trusted community or family members about their experiences and knowledge related to different types of transportation and fuels, and criteria to determine which type of fuel is more desirable than another. This activity helps to support the *development of additional questions* as well as aiding *problem definition* (SEP: 1.1, 1.8), building on prior work in *Oysters Unit*.

After creating the Driving Question Board, students brainstorm *investigation ideas and data needs to help answer their questions* (SEP: 1.1, 1.8).

In this lesson, students will co-construct a definition for the following term, which they should add to their Personal Glossaries: *carbon-based fuels*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

We are not expecting most students to know the structure of an internal combustion engine in this lesson. Investigating that structure will be the focus of Lesson 2.

Most students may not bring up energy transfers beyond heat for a combustion reaction. Additional energy transfers around combustion reactions, such as sound or light, will be explored in Lesson 2 (DCI: PS3.A.2).

In this unit, students will focus mainly on fuels used in the transportation sector, rather than the transportation modes and fuels that students use personally (i.e., as part of a personal carbon footprint). Although students need to recognize that climate change can be addressed and that they have the ability to help make that happen, carbon footprints and other individual-centric tools have been used as part of campaigns to shift responsibility for climate change from major emitters to consumers. Therefore, it is most important to help students understand the mechanisms behind climate change (previously built in *Polar Ice Unit*) and proposed solutions (Lesson Sets 1 and 2 in this unit), and to help them consider what changes might be made at the systemic level and advocate for their vision of an improved system (Lesson Set 3). For more information, see:
Windschitl, M. (2023). *Teaching climate change: Fostering understanding, resilience, and a commitment to justice.* Harvard Education Press.
A number of resources from this book are available at https://climate-change-educator.org/.

LEARNING PLAN for LESSON 1

1 · NAVIGATE

4 min

MATERIALS: None

Identify global problems. Display **slide A.** Discuss the related questions on the slide as a class.

Suggested prompt	Sample student response
What are some of the issues we have studied this year related to global problems?	Global warming and climate change. Rising sea levels, displaced communities, and polar ice melt. Ocean acidification and impacts on oysters from increased carbon dioxide in the atmosphere.
What solutions might help with these problems?	Reflecting sunlight by sprinkling whiter material over dark surfaces near the poles. Building sills (underwater walls) to block warm salt water flow from reaching large glaciers. Growing kelp forests between sensitive oyster ecosystems and the larger ocean. Adding crushed oyster shells to the ocean.
What was the underlying chemical cause in the environmental issues we examined?	Humans impacting their environment negatively. Carbon dioxide emissions.

Point out that it was important not only to understand the scientific ideas behind these various problems and solutions, but to use engineering thinking as well. Suggest that we prepare to take both a scientific and an engineering-based approach in this unit, to help us start thinking about additional solutions that could contribute to solving these global problems.

2 · CONSIDER CAUSES OF CO2 EMISSION CHANGES

6 min

MATERIALS: science notebook

Analyze graph of electric power and transportation emissions. Display **slide B**. Read the statement on the graph, *"These two sectors account for over 60% of worldwide CO_2 emissions."* Have students discuss what they notice and wonder about the graph with a partner for two minutes. Students will not report out for this slide.✱

ADDITIONAL GUIDANCE

If students would benefit from recording what they notice and wonder about the graph on **slide B**, encourage them to create a Notice and Wonder chart in their science notebooks.

Brainstorm solutions. Display **slide C.** Have students discuss the two related questions on the slide with a partner, spending a minute on each question. Then take two minutes to discuss these questions as a class.

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

Throughout this lesson, students will be engaging with various data sources. Keep students focused on what this data tells us about a problem in the world and potential

Suggested prompt	Sample student response
What technological solutions could explain the decrease in CO_2 emissions from electric power since 2010?	More wind and solar power. Less coal plants. Maybe more nuclear plants, dams, or new types of power plants are going up? Higher efficiency devices (e.g., LED lights and appliances).
How could science and engineering help us develop new solutions to reduce CO_2 emissions from transportation?	Designing and building electric cars. Constructing better mass-transit systems. Requiring more efficient gas cars. Building infrastructure for ethanol production and use.

Navigate to thinking about differential impacts. Ask students, *Where in the world do you think these solutions could have the greatest impact?* Accept all responses.

solutions (SEP: 4.5). Although this practice element is not assessed here, it will be an important idea later in the unit.

3 · ANALYZE PER-CAPITA EMISSIONS DATA

6 min

MATERIALS: None

Reflect on data from the countries with the highest per-capita emissions. Display **slide D** and lead a brief discussion of the prompts. If necessary, give students a moment to turn and talk before sharing out with the class.

Suggested prompts	Sample student responses	Follow-up questions
What do we notice about these data?	The United States is very high. We hear about China's emissions a lot, but per person it is below the global average.	*What do a lot of these countries have in common?* *Why are the most populous countries (China, India) not as high on this list?*
What might explain these rankings?	Driving. People in countries with more wealth might fly more on average. Maybe vehicles are more fuel-efficient in some countries.	*Which types of vehicles do we use for transportation that might be most responsible? Why?*

Problematize the fuel source. Say, *To help us think of possible engineering solutions to bring transportation emissions down, let's consider which vehicles are actually responsible for emissions in the United States.*

ALTERNATE ACTIVITY

If you are not in the United States, you may replace the data on **slide E** with data from your own country. Likely starting points for a search include governmental databases, local university programs that focus on climate or environmental science, or sites like OurWorldInData.

Analyze a chart on CO_2 emissions by transportation type. Display **slide E.** Give students a half minute to orient to the data shown on the slide, then use the prompts below to lead a discussion.

Suggested prompt	Sample student response
What do we notice about these data?	Personal vehicles are the largest source of carbon dioxide emissions. Commercial trucks and buses make up a smaller, but significant, share of emissions.
What ideas do the data give us for how science and engineering could help us develop solutions to reduce CO_2 emissions from transportation in the future?	Accept all responses.
Do you think all of the types of vehicles in these different areas use the same types of fuel?	Accept all responses.

Summarize student ideas. Highlight areas where students have competing ideas and suggest we look at more data.

ADDITIONAL GUIDANCE

The United States is atypical globally for its relatively high reliance on personal vehicles to help people move around. Although this was not always the case, it has had significant consequences for carbon dioxide emissions and safety, as well as land use, making both large and small cities more spread out, more car-dependent, and less walkable. This unit does not address how these shifts unfolded historically, but be sure to draw distinctions between personal vehicles, solutions to move freight like large trucks and trains, and public transit modes like buses. This will help lay groundwork for students to imagine alternate transportation systems in their final project. See the following for more information:
https://yaleclimateconnections.org/2023/10/american-society-wasnt-always-so-car-centric-our-future-doesnt-have-to-be-either/
http://www.autolife.umd.umich.edu/Environment/E_Casestudy/E_casestudy.htm

4 · EXPLORE DIFFERENT TYPES OF FUELS

21 min

MATERIALS: science notebook, Fuel Data Cards

Motivate exploring the possibilities for fuels further. Say, *The fuels we use today are not necessarily the same fuels we used 50 or 100 years ago for these different types of transportation. And the fuels we design our next generation of vehicles to use may be different from the ones we use today. There are, in fact, some new types of fuels that are being tested as possible alternatives to the ones we currently use in all kinds of vehicles. Let's prepare to explore some of the types of fuels that have been used, are being used, or are under development for possible use, to see what questions they raise for us.*

Orient to one fuel data card. Say, *In a moment you will start exploring 15 different fuel data cards, each providing information on one type of fuel. Let's take a moment to orient to one of these fuel cards.* Display **slide F.** Give students a minute to orient to the card.

Ask, *What information contained on the card could help us figure out which fuels we might want to consider for our next-generation vehicles?* Look for students to suggest:

- Amount of carbon emissions
- Source materials
- Energy released
- Other trade-offs

✱ ATTENDING TO EQUITY

Universal Design for Learning: Allowing for student choice of the three fuel data cards they will examine as well as how to sort their cards, helps support *engagement*. Individual choice and autonomy are leveraged in this activity. Students will compare their sorting ideas in small groups, which also supports *engagement* by fostering collaboration and community to identify patterns in CO_2 sources.

ADDITIONAL GUIDANCE

There are 17 Fuel Data Cards provided, but two--wood and coal--are optional. If students have particular interest in older technologies that use these fuels, you may distribute them as the idea of the steam engine may be leveraged to support student sensemaking around nuclear fission. However, the unit as written does not answer specific student questions about these fuels, and they may be confusing to some students.

Among other data, the cards provide information about "energy released," or energy per unit substance. The former name was chosen because it is simple for students to use and refer to. This measure was chosen instead of others, such as energy density (energy released per unit volume) because it aligns nicely with the units of bond energy introduced in Lesson 7.

Individually orient to additional fuel data cards. Have students move into small groups and distribute the Fuel Data Cards. Display **slide G.** Read through the directions on the slide (also listed below) and give students two minutes to individually complete the task.✱

1. Choose 3 cards at random from the deck of fuel data cards.
2. Take two minutes to read through them and jot down at least 3 questions you have about the information on the cards.

Sort fuel data cards in small groups. Display **slide H.** Have students develop a table like the one shown on the slide in their science notebooks. Tell students they will have 13 minutes to work as a group to sort the fuel data cards in two different ways. Students should record their categories and observations for each round, with questions captured below. Assign each group a column (Input or Output) to sort by in the second round. Tell students to sort the cards by any way they choose first, then by something in their assigned column. Throughout, encourage students to look for patterns.✱

ADDITIONAL GUIDANCE

The fuel data card for LP gas ("propane") includes the chemical formulas for both propane (C_3H_8) and butane (C_4H_{10}). While these are two chemically different fuels, they are both forms of liquified petroleum gas. In Lesson 2, a distinction is made for both substances as students balance chemical formulas for combustion reactions.

Share fuel data card sorting. Students can remain in their groups during this whole-class discussion. Display **slide I**.

Suggested prompt	Sample student response
What different categories did your group use to sort the fuel data cards?	Accept all responses. As groups share, invite others to show their agreement (e.g., raise hand, thumbs up).
We sorted the cards lots of different ways. Of these fuels, which seems like it would be the biggest culprit in terms of carbon dioxide emissions?	Probably gasoline, since it's most commonly used and releases carbon dioxide. Diesel is up there too.
What are some noticings your group had?	Most of the fuels were hydrogen and carbon. Very few fuels did not contain hydrogen or carbon.
What are some wonderings your group had?	What does "energy released" mean? We were wondering about why fuels that have high carbon emissions are used so often.

Say, *Many of you noticed that the majority of the fuels in the data cards contained hydrogen and carbon. We call these carbon-based fuels. Take a moment to add the term* carbon-based fuels *to your Personal Glossaries.*

Summarize group wonderings. Highlight those that consider energy. Suggest that it might be helpful to begin to consider how the fuel provides the energy to move the vehicle.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Earlier in the lesson, students examined graphical representations of data to begin to think about *patterns in carbon dioxide emission sources* and types of transportation. Students should use patterns in the information contained in the fuel data cards to sort them into various categories. As groups work to sort their cards, ask them *what patterns in the fuel data cards* are they using to inform their sorting. (CCC: 1.3)

ADDITIONAL GUIDANCE

The term *carbon-based fuels* was selected because it accurately describes all fuels that contain carbon. A seemingly similar term, *hydrocarbons*, technically refers to organic compounds that contain only hydrogen and carbon.

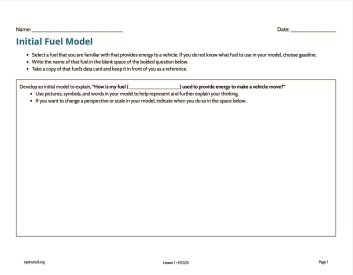
5 · DEVELOP INITIAL MODELS

8 min

MATERIALS: *Initial Fuel Model*, Fuel Data Cards

Develop an initial model. Display **slide J**. Distribute *Initial Fuel Model*. Say, *Let's try to develop an initial model to explain how a fuel is used to provide energy to make a vehicle move.*

Review the directions on *Initial Fuel Model*. Suggest that students use gasoline for their model if they do not have a preference, given that it is the most commonly used fuel in vehicles. Display **slide K** for students that use gasoline. Give the remaining class time for students to work on developing their individual model. Let students know that they will spend time with a partner during the next class to share their models.


Name: _____ Date: _____

Initial Fuel Model

- Select a fuel that you are familiar with that provides energy to a vehicle. If you do not know what fuel to use in your model, choose gasoline.
- Write the name of that fuel in the blank space of the bolded question below.
- Take a copy of that fuel's data card and keep it in front of you as a reference.

Develop an initial model to explain "How is my fuel (_____) used to provide energy to make a vehicle move?"

- Use pictures, symbols, and words in your model to help represent and further explain your thinking.
- If you want to change a perspective or scale in your model, indicate when you do so in the space below.

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ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students identify components of the vehicle system, such as fuel or battery, engine, and exhaust/air. (SEP: 2.3)

What to do: At this point, encourage students to add ideas about what they think may be happening based on their prior knowledge and the lesson so far. Students may begin to consider changes in matter, energy transfer, and force thinking, but students will revise their models on day 2 to explicitly include these ideas using the M-E-F poster. For now, keep the focus on the components of the model and push students to identify whether they have evidence for these components. It is okay if they do not, but then encourage them to identify these ideas as areas of uncertainty when they build the class consensus model on day 2.

Building toward 1.A.1 Develop a model based on evidence (chemical formula, energy released, and carbon dioxide emission) to illustrate the matter change, energy transfer, and force interaction relationships between the components of the system to explain how a fuel (matter) is used to provide energy in a vehicle system to make it move. (SEP: 2.3; DCI: PS3.A.2, PS3.A.4; CCC: 5.3)

End of day 1

6 · REFLECT ON COMMUNITY AGREEMENTS

3 min

MATERIALS: Community Agreements

Individually reflect on Community Agreements. Display **slide L.** Remind students that we are about to engage in a key sensemaking activity, where we work together to identify everything we agree on as well as areas of uncertainty or disagreement in our initial models. Ask students to take one minute to individually reflect on the Community Agreements as indicated on the slide and choose one area that they will personally work on for the rest of class.✱

✱ ATTENDING TO EQUITY

Building classroom culture: Having students select a personal Community Agreement for their work today will help to reinforce for

Discuss focal Community Agreement with a partner. Display **slide M.** Cue students to take one minute each to share what they chose with a partner and why.

them the importance of the class agreements. It also creates an opportunity for students to actively participate in group work and to self-regulate their participation in group activity. Over time, these Community Agreement reinforcing strategies can help to build a positive group-work culture by encouraging students to identify the skills, interest, and knowledge they have that can strengthen the group, as well as help to ensure that all students are actively participating in sensemaking.

7 · COMPARE INITIAL MODELS USING M-E-F THINKING

7 min

MATERIALS: *Initial Fuel Model*, colored pencils, M-E-F poster

Compare initial models with a partner. Display **slide N** and have the M-E-F poster visible. Read through the instructions on the slide and ask students if they have any clarifying questions.

After three minutes, cue students to take three more minutes to add any new ideas to their model by annotating it with arrows and words in different colors to represent new thinking, or to sketch a new model.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students draw on evidence and previous science understandings to show how vehicle components interact. (SEP: 2.3)
- Students trace energy as it moves between different components of the vehicle system. (DCI: PS3.A.2; CCC: 5.3)
- Students identify locations of forces (fields) within the vehicle system. (DCI: PS3.A.4; CCC: 5.3)
- Students consider how changes in matter result in changes in energy and forces. (DCI: PS3.A.2)

What to do: At this point, students' ideas about energy, matter, and fields may not be entirely correct. Focus probing questions on ensuring those ideas are present to the extent that they can be justified by evidence from the lesson and students' experiences.

If some students record ideas related to only two different perspectives at this point, that is fine. Make a copy of these and return them to students to reference in Lesson 2. They will develop additional ideas for explaining what is happening in this system by the end of Lesson 2. If students have only a matter perspective shown, prompt them to label their models with key locations where they think energy transfers or force interactions are occurring. Given prior experiences students should correctly identify evidence of energy (e.g., light, sound, temperature increases) and tie it to particle motion where appropriate. Students are familiar with fields and may bring them into their models. If they do not, it is particularly important to refer back to *Electrostatics Unit* in Lesson 4 to remind students of prior sensemaking using fields.

Building toward 1.A.2 Develop a model based on evidence (chemical formula, energy released, and carbon dioxide emission) to illustrate the matter change, energy transfer, and force interaction relationships between the components of the system to explain how a fuel (matter) is used to provide energy in a vehicle system to make it move. (SEP: 2.3; DCI: PS3.A.2, PS3.A.4; CCC: 5.3)

8 · DEVELOP AN INITIAL CLASS CONSENSUS MODEL

15 min

MATERIALS: *Initial Fuel Model*, science notebook, chart paper, colored markers

ALTERNATE ACTIVITY

At this point in the year, students should be practiced in Scientists Circles. You may wish to use this opportunity to allow a different student to lead the discussion around each slide O-R, using the prompts provided. Provide each student with a couple of key talk moves to use for following up the prompts--for example, "Say more," "Agree/disagree and why," and "Add on." Refer to *Initial Model Ideas* for guidance on when you can push students to clarify their thinking in some of the most important areas for future sensemaking.

Develop an initial consensus model. Display **slide O**. Have students bring their science notebooks and *Initial Fuel Model* to a Scientists Circle. Facilitate a discussion around the consensus model. Work together as a class to develop an initial consensus model to explain, *How do different fuels provide energy to make a vehicle move?* Add this question as a title to the chart paper you use to document students' ideas.✱

KEY IDEAS

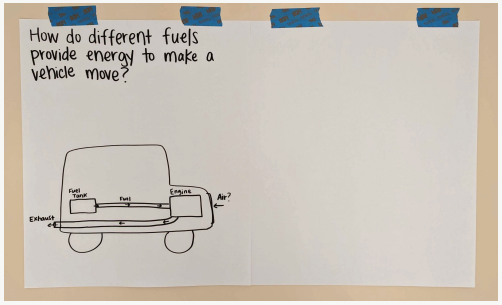
Purpose of this discussion: Capture ideas that fall into different ways of making sense of the phenomena from a matter, energy, and forces perspective. It is not imperative to categorize the ideas as they are shared; rather, use each category as a way to prompt for different ideas represented in students' models. Indicate areas of uncertainty or competing ideas with a question mark after the idea (e.g., "air flow into the engine?").

Listen for these ideas:

- Matter flows into the vehicle.
- Matter flows out of the vehicle.
- There are some sort of particle-level changes in the matter.
- Energy changes/transfers must occur in the engine.
- Force interactions occur inside or outside the engine.

An example model and a more comprehensive list of student ideas may be found in *Initial Model Ideas*

Suggest that since we likely chose many different fuels to develop our individual models, we should first develop a class model for the types of fuels that most of us used or that have a lot in common. Ask students how many of them chose a fuel that needs to be refilled at a gas station. Suggest that we try to develop a model for these fuels first. At each step during the model development, ask students who may have developed initial models for non-carbon-based fuels, like batteries or uranium, what is similar or different.



Add a color-coded key for changes in matter, energy changes and transfers in the system, and forces, so that you can use a different color of marker to indicate when you shift to an energy or forces perspective.

Identify matter flows into the vehicle. Display **slide P** and ask, *How does matter flow into the vehicle?* Listen for these ideas:

- *For carbon-based fuels:* Fuel goes from a storage tank in the vehicle (as a gas or a liquid) to the engine.
  - Optional: Air or oxygen flows into the engine.
  - This will also provide an opportunity to add some initial parts to the model (a fuel tank, a car body, wheels, an engine).
- *For other fuels:* Because students may be less familiar with these technologies, record whatever ideas they have. When possible, map to parallel parts of a more familiar vehicle. Students may be unsure of the states of matter or the particular substances that are involved.✱

✱ ATTENDING TO EQUITY

Early in the unit, the initial consensus model should be inclusive. Even if the majority of the class focused on a particular type of fuel, mapping other ideas onto related areas of the class model is important to show all students that their ideas are valued. Similarly, areas of disagreement can be indicated with question marks, or with competing ideas drawn alongside one another.

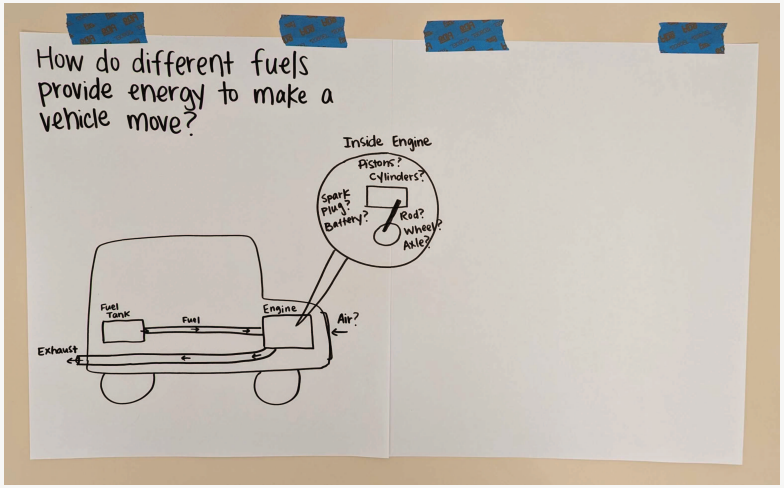
✱ ATTENDING TO EQUITY

This discussion should be student-centered. The teacher should encourage students to think through the questions and support this discussion as necessary with partner talk. Do not tell students the "listen-for" responses.

Identify matter flows out of the vehicle. Ask students to identify important matter flows out of the vehicle. Listen for these ideas:

- *For carbon-based fuels:* Exhaust or emissions come out of the tailpipe. (Ask students to be specific, or be sure to include CO_2.)
- *For other fuels:* They emit no byproducts, but uranium and batteries may include waste material(s) associated with disposal.

Identify other important structures in the vehicle. Have students identify any additional structures inside the engine that they included in their models. Before adding these to the initial consensus model, make sure the majority of students are in agreement. These structures may include: piston(s), piston rod, spark plug, battery, or other parts that connect the engine to the drive train or wheels.

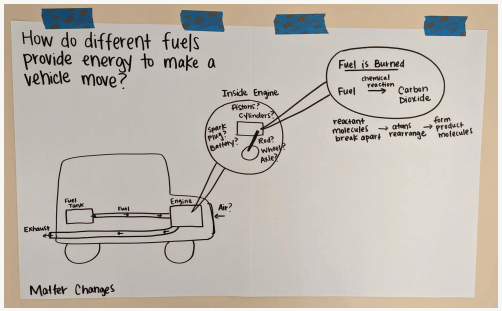


ADDITIONAL GUIDANCE

Some students may be involved in engine repair classes and this is a great opportunity to capture their ideas. Since many students may not be familiar with engine components, it is also important to leave question marks around whatever parts students may be unsure about. Include and keep this representation minimal, to help emphasize that these are things that not all of us had in our initial models. This will help motivate some questions about this part of the system, which is a focus of Lesson 2. If students modeled other fuels such as lithium, hydrogen, and uranium, capture a list of any structures they say are important components of those systems, below the class model.

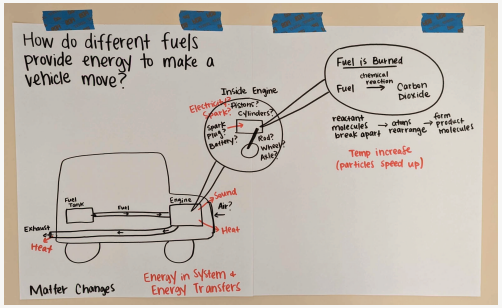
Identify particle-level changes in the matter. Ask students specifically about any particle-level changes they showed happening in the system. Listen for these ideas:

- *For carbon-based fuels*: Burning or combustion. Build off this idea by asking what type of change is happening at a particle level--what is happening to the atoms that make up the molecules? Students should recognize that molecules break apart and the atoms form new molecules.
- *For batteries:* Electrons are moving off of some material or substance in the battery.
- *For other fuels:* It is less likely that students will identify a particular particle-level process. Again, include these ideas with question marks to reflect any areas of uncertainty.



ADDITIONAL GUIDANCE	Students should be somewhat familiar with combustion reactions based on their prior work in high school in *Fires Unit*, and in middle school in *Maple Syrup Unit* and *Droughts and Floods Unit*. If they are not, that is okay as details will be added in Lesson 2.

Identify energy changes and transfers in the engine. Display **slide Q**. Ask students specifically about changes in energy or energy transfers they represented in the system. Students are likely to say that:



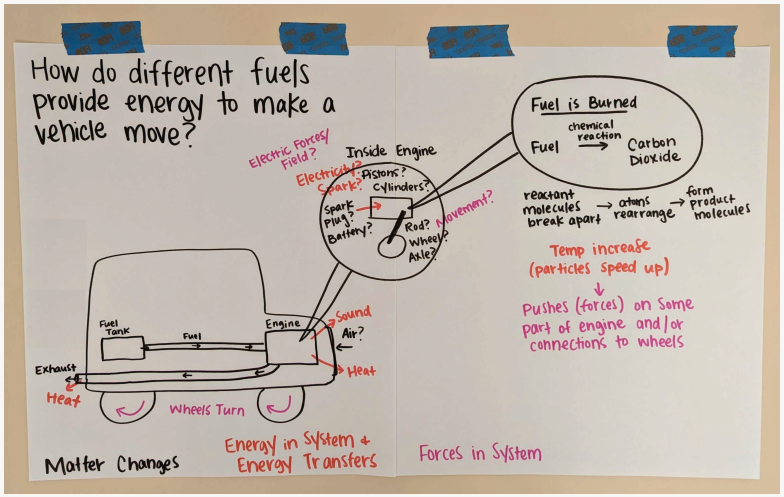
- *For carbon-based fuels:* Energy is somehow released in burning and, when there is a temperature increase, the speed of the particles that make up the matter increases.
- *For other fuels:* Energy must be released somehow--from inside the battery or fuel cell, or perhaps because of something "nuclear" happening with uranium.

Be sure to press on the idea of particle speed increasing with increases in temperature. This is an idea that students established in *Polar Ice Unit* and it is an important one to resurface in the model.

Students may also suggest other evidence of energy transfers:

- The engine makes a sound.
- Energy is somehow transferred from the engine to the wheels (or another part of the vehicle that makes it move, such as a propeller).
- The collisions between particles transfer energy (e.g., conduction).
- A battery provides the energy in a spark to start many combustion engines. Students who are familiar with diesel may suggest that this is not always needed for other fuels.

Include any ideas where the majority of students are in agreement. Again, include question marks next to ideas where there is not consensus.



Identify important force interactions in the system. Display **slide R.** Ask students specifically about forces in the system. It is less likely students will have taken a forces perspective. If students do not have much to say about force interactions, acknowledge students' uncertainty. If they do take this perspective, one or more of these ideas may come up:

- Particles in the engine collide with and push on piston surfaces.
- Solid structures in the engine push/pull on each other through contact forces (e.g., crankshafts attached to pistons, gears, wheels turning, etc.).
- Electrostatic forces between subatomic particles, atoms, or molecules may increase, as evidenced by sparks.

Some ideas, like wheels turning, may be identified and represented as an energy transfer, a force interaction, or both.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Initial Model Ideas* for guidance.

What to do: Students may identify some or all of the ideas listed in *Initial Model Ideas*. Use clarifying questions and support student use of the M-E-F poster in considering matter, energy, and forces to help students make their thinking around these explicit and visible.

Building toward 1.A.3 Develop a model based on evidence (chemical formula, energy released, and carbon dioxide emission) to illustrate the matter change, energy transfer, and force interaction relationships between the components of the system to explain how a fuel (matter) is used to provide energy in a vehicle system to make it move. (SEP: 2.3; DCI: PS3.A.2, PS3.A.4; CCC: 5.3)

9 · ASK SCIENCE-RELATED QUESTIONS ABOUT THE PHENOMENA

3 min

MATERIALS: 3x3 sticky notes, colored markers, science notebook

Record questions about the science ideas of the phenomena. Display **slide S**. Distribute sticky notes and markers to students.

Review the directions on the slide and give students a moment to record questions.✱

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students ask questions related to fuels, emissions, energy released, or climate change. (SEP: 1.1; DCI: PS3.A.2, ESS3.C.2)
- Students ask questions about changes in matter, energy transfer, or forces that relate to what happens inside an engine. (SEP: 1.1; CCC: 5.2)

What to do: If students struggle to come up with questions, direct them back to their initial models, their notes from the fuel data cards, and the initial class consensus model. Students may not ask questions that use the exact language of the disciplinary core ideas, and that is okay, but students' questions should connect to matter and energy changes and forces when fuel is used for transportation. Students will have an opportunity to ask more questions about the engineering problem shortly. Although this activity was set up to help students generate science questions, it is okay if they generate some engineering questions. They will be more careful about that distinction after building the Driving Question Board (DQB).

Building toward 1.B.1 Ask questions that arise from and seek additional information about: patterns in data related to fuel use in transportation; attempts to explain how matter (fuel) and energy transfer in a vehicle to produce movement; and attempts to identify criteria and constraints to inform design solutions for next-generation vehicle fuel use. (SEP: 1.1, 1.8; DCI: PS3.A.2, ESS3.C.2; CCC: 5.2)

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Student *questions* should come from *careful observation of the phenomena* they have experienced so far. The information they should consider includes the graphs they have examined, the fuel data cards, and the initial class consensus model. Prompt students to think about how they form their questions to ensure that these questions either *clarify what they have observed* or *seek additional information*. (SEP: 1.1)

10 · BRAINSTORM CRITERIA AND CONSTRAINTS TO EVALUATE FUTURE FUELS AND GENERATE QUESTIONS

15 min

MATERIALS: science notebook, *Initial Fuel Model*, Fuel Data Cards, 3x3 sticky notes, colored markers, chart paper markers, "Criteria and Constraints for Evaluating Fuels for Transportation" poster

Discuss related phenomena. Say, *We just recorded some science-related questions after thinking about how these fuels work. Let's think back to the graphs we initially saw showing projected trends of sources of carbon emissions. Remember, this is where we started to think about ways that engineering and science can help decrease the amount of CO_2 emissions from transportation. So, let's consider what we are trying to figure out from an engineering perspective.*

Display **slide T**. Say, *Turn and talk with the person next to you about how people typically get around and why they choose the vehicles and fuels they do.✱ Record criteria and constraints in your science notebooks. You will have five minutes to complete the three questions*:

- Right now, how do people typically get around?
- What criteria and constraints influence their decisions about what vehicles and fuels they use?
- What do fuels and our transportation system *have* to do to "work"?

After five minutes, ask for a few partners to share some of their brainstormed criteria and constraints. As students share, encourage others to show agreement using non-verbal signals. Suggest that these criteria and constraints could help us evaluate fuels and their role in a future transportation system. Keep track of them on a piece of chart paper titled, "Criteria and Constraints for Evaluating Fuels for Transportation." In later lessons, this will be referred to as the *Criteria and Constraints* poster.

Any ideas students identify at this point are useful, and students will have opportunities to add criteria and constraints throughout the unit. Some may include:

- Lowest possible cost
- Lowest possible carbon dioxide emissions or must emit no carbon dioxide
- Highest possible energy released
- Have to be readily available when we need to get around

Introduce the Avoid-Shift-Improve framework. After students share, ask: *Do people always make the same choices about which vehicles or fuels to use? What is different about their thinking?* Listen for the idea that people have different needs or wants. Point out that as we think about a future transportation system, we also have a variety of options about how we proceed, but we want to keep our criteria and constraints in mind with all of them. Note that engineers might take different approaches when solving a problem, which is captured in these engineering goals. Display **slide U** and give students a minute to read the definitions. Elicit ideas about what these might look like in a fuel context. Accept all responses, which may include:

- *Avoid:* Travel less; do school and meetings online; walk instead of driving.
- *Shift:* Use a fuel in personal vehicles that is better than gasoline.
- *Improve:* Make vehicles more fuel efficient so that less carbon dioxide is released.

Ask engineering design-related questions about the phenomena. Display **slide V.** Review the directions on the slide. Distribute sticky notes and colored markers to partner groups. Ensure that each student saves at least one sticky note from the set their group generated to share in the DQB activity next class.

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Students considered interactions of components while developing their initial and class consensus models. Support them in using these interactions when identifying criteria and constraints related to the design problem of reducing carbon emissions from the transportation sector. Criteria/constraints may include social, technical, and/or environmental considerations (SEP: 1.8).

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students ask questions about changes in matter, energy transfer, or forces that relate to what happens inside an engine. (SEP: 1.1; CCC: 5.2)
- Students identify criteria and constraints and ask questions about the benefits or trade-offs of different fuels. (SEP: 1.8; DCI: ESS3.C.2)

What to do: If students struggle to come up with questions, direct them back to their initial models, their notes from the fuel data cards, the initial class consensus model, and the "Criteria and Constraints for Evaluating Fuels for Transportation" poster. As students share questions and build the DQB, look for types of questions students do not ask (e.g., questions about forces or questions about benefits and trade-offs). If a large group of questions is "missing," ask one of your own and ask if anyone else has a similar question. This will likely spark at least one or two students to add a similar question of their own.

Building toward 1.B.2 Ask questions that arise from and seek additional information about: patterns in data related to fuel use in transportation; attempts to explain how matter (fuel) and energy transfer in a vehicle to produce movement; and attempts to identify criteria and constraints to inform design solutions for next-generation vehicle fuel use. (SEP: 1.1, 1.8; DCI: PS3.A.2, ESS3.C.2; CCC: 5.2)

11 · NAVIGATE

2 min

MATERIALS: science notebook

Introduce home learning. ✱ Display **slide W.** Suggest that since we are considering design solutions that will affect a lot of people, we should start finding out from those interested parties what criteria they think are important. Tell students that they should plan tonight to discuss the three questions on the slide with a trusted member of their community or family. Explain that next class, we will share the ideas they identified. Point out that these new ideas may lead to the development of additional questions we want to add to the DQB. Make slides available to students or have them record these prompts so that students can reference them later.

✱ ATTENDING TO EQUITY

Universal Design for Learning: This home learning is used to broaden students' thinking to related phenomena and leverage the experiences and priorities of people they have relationships with outside the classroom. Providing an opportunity to connect to the context of their community helps the phenomena and design solutions become more personally meaningful to students and supports student *engagement*. It also gives students an opportunity to talk about the phenomena with family members and other community members.

End of day 2

12 · NAVIGATE

3 min

MATERIALS: science notebook, "Criteria and Constraints for Evaluating Fuels for Transportation" poster, chart paper markers

Share home learning findings with a partner. Reference the "Criteria and Constraints" poster from the last class. Display **slide X**. Have students turn and talk with a partner to share what they found out. If you have time, have a few students share and add any new criteria and constraints they suggest to the poster.

ADDITIONAL GUIDANCE	Even in cases where students did not get a chance to interview someone, this activity prompts students to consider what members of their community might say. This provides a meaningful framing for thinking about the initial criteria and constraints list generated the day before.
ALTERNATE ACTIVITY	**Extension opportunity:** Students who talked with people who have lived in the community a long time may have learned that public transit was once much more common in their area. Many communities, of various sizes, that are now auto-centric once relied more heavily on streetcar networks or intercity rail. You may encourage students who have questions in this subject to investigate it further, or coordinate with social studies colleagues to examine your area's history of transportation from a historical, economic, or human geography lens. As students investigate this history, encourage them to consider who is impacted, and how, when non-auto transportation options decrease. (SEP 1, 3).

13 · BUILD THE DRIVING QUESTION BOARD

21 min

MATERIALS: 3x3 sticky notes, colored markers, science notebook, DQB

Review sticky notes. Say, *In light of the ideas that the people we talked to outside of class shared, you may have some new questions or revisions to your old questions that you want to make.* Display **slide Y**. Distribute additional sticky notes to students. Give students two minutes to review, revise, and record any additional questions on sticky notes.

Build the Driving Question Board. Have students form a Scientists Circle around the DQB. Display **slide Z** and ask students to take out their sticky-note questions. Display **slide AA** and review the directions for how to build the DQB. See *Supporting Student Questions* for likely student questions that relate to different lessons in the unit. Students will likely organize the questions by the fuel involved, or, when no specific fuel is mentioned, by their questions and concerns about changes to the transportation system.

14 · IDENTIFY SCIENCE AND ENGINEERING QUESTIONS

6 min

MATERIALS: two colors of small sticky dots (preferably green and blue), DQB

Distinguish between science and engineering questions. Display **slide BB.** Ask two students to read the statements about science and engineering on the slide. Then ask: *When have we practiced each of these in the course?* Listen for students to suggest that we have usually been engaging in science, but we have also thought about engineering a bit in *Polar Ice Unit* and *Space Survival Unit*, and a lot in *Oysters Unit* when we were defining the problem and proposing possible solutions.

Place a pile of green and blue sticky dots next to the DQB. Instruct students to reflect on whether the questions they asked were more about understanding the science behind fuels or about engineering solutions to improve our transportation system.

Have students return to their seats after marking their question(s) with sticky dots.✱ Elicit what students notice about the patterns of science and engineering questions. Depending on how students organized the DQB, question types may or may not line up with existing categories--either possibility is fine.

✱ ATTENDING TO EQUITY

Universal Design for Learning: The opportunity to move in this activity benefits learners by focusing neurodivergent students and facilitating gross motor movement to improve oxygen flow to the brain. This supports student *engagement*.

15 · BRAINSTORM AND SHARE IDEAS FOR INVESTIGATIONS AND DATA NEEDED

12 min

MATERIALS: science notebook, chart paper, chart paper markers

Brainstorm investigations and data needed. Say, *Let's consider possible investigations and data we would need to answer our questions.* Display

✱ ATTENDING TO EQUITY

slide CC. If students brought their notebooks to the Scientists Circle, they can remain in the circle for this activity. If students could benefit from a bit of movement, have them return to their seats or a nearby writing surface for this step. After four to five minutes, have students return to the Scientists Circle.

Share all investigation and data ideas. Display **Slide DD**. Ask students to share all the ideas they have listed in their notebooks, starting with those related to scientific principle questions. Encourage students to snap whenever they hear an idea suggested that is the same as one on their own list, so students know we have captured an idea where there is agreement.✱ Ask students to put a checkmark on such ideas as they are shared, to keep track of which new ideas on their list they can move on to and share next.

As students share their ideas for investigations and data we need, record them on a sheet of chart paper.

Repeat the process for ideas for investigations and data we need for the engineering design problem questions. Continue until all students have had a chance to share all of their ideas.

Building classroom culture: The goal of this step is to establish that we are developing a shared "mission plan" in this stage of the work. Providing public feedback that others' ideas are getting captured whenever a single person shares their own, helps to support this. Your class may already use an alternate signal for such feedback, such as a visible hand signal like the ASL sign for "agree". Change **slide DD** to reflect the signals that your class has adopted earlier in the year.

16 · REFLECT ON TACKLING GLOBAL PROBLEMS AND SOLUTIONS

3 min

MATERIALS: science notebook

Complete an exit ticket. Remind students that we have spent many units this school year examining the science around global problems related to climate change. Point out that scientists and engineers are working to help solve these problems, to lessen the impacts of or possibly slow climate change. Explain that our goals in this unit are similar.

Display **slide EE** and read the prompts on the slide and below:

- How are you feeling about this unit?
- What do you hope to figure out as we try to understand the different fuels we have seen in this lesson?

Give students the remaining time in class to complete the exit ticket in their science notebooks. Before the next class, review student responses and the unit storyline and consider how they might be used to support navigation between lessons in the unit. Also note places in the unit where students may need additional social-emotional support.

ADDITIONAL GUIDANCE

Students studying global problems like climate change may experience a lot of anxiety or guilt. The purpose of this exit ticket is to provide students space to share these feelings. If you have time, you could ask a few students to share their feelings or have a class discussion around students' feelings about climate change.

Several online resources including the *Emotional Resilience Toolkit for Climate Work (Version 1.5)* https://static1.squarespace.com/static/5f74c9f17e186b15c051629e/t/5fadc42316947a58febe7782/1605223460375/Copy+of+Copy+of+Emotional-Resilience-Toolkit-for-Climate-Work-v1.5-04Oct19-2.pdf offer other tools to help students manage their emotions when studying climate change (Climate Therapy Alliance - Pacific Northwest, 2019).

LESSON 2: What is happening to the fuels inside the engine to make the vehicle move?

PREVIOUS LESSON

We analyzed data of different fuels used by different types of vehicles. We developed models to explain how fuels provide energy to make vehicles move. We identified criteria that might make one fuel more desirable to use than another. We developed a Driving Question Board and ideas for investigations and data we need to answer our questions.

THIS LESSON

INVESTIGATION

3 days



We examine a series of diagrams that show the important components of a gasoline-powered vehicle, including the cylinder system. We analyze the changes that occur using our M-E-F poster. We test some ideas by burning ethanol in several configurations, and we model changes in matter (using balanced equations) and changes in energy and forces (using a particle model). We develop a model for how gasoline-powered engines work, then analyze data to determine whether there is a more optimal alternative fuel for transportation. Finally, we examine how diesel engines are different from gasoline engines. We start our Progress Trackers to close the lesson.

NEXT LESSON

We will revisit phenomena to look for patterns in air property changes. We will analyze air property data for trends and use the Combined Gas Law to determine pressure in the fire syringe and diesel cylinder. We will use M-E-F thinking to determine the cause of the air temperature increase.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

2.A Construct and revise an explanation based on models showing the structure and function of vehicle components that explains how chemical processes release energy, allowing the vehicle to move. (SEP: 6.2; DCI: PS1.B.1; CCC: 6.1)
2.B Develop, revise, and use models based on evidence to identify relationships between changes in matter and energy transfers that take place in a vehicle as a result of the combustion of fuel. (SEP: 2.3; DCI: PS1.B.1; CCC: 5.2)
2.C Analyze data using CODAP to identify patterns in carbon-based fuel characteristics that optimize the successful movement of a vehicle when burned in an internal combustion engine. (SEP 4.6; DCI: PS1.B.1; CCC 1.3)

WHAT STUDENTS WILL FIGURE OUT

- The inputs of a combustion reaction are fuel and oxygen, and the outputs are carbon dioxide and water vapor.
- These changes in matter result in energy being transferred out of the reaction, which can be observed as a temperature increase.
- The release of energy when fuel combusts in a vehicle engine results in forces applied to various parts of the vehicle, which cause the wheels to turn.
- Diesel and biodiesel fuels provide more energy and less CO_2 emissions, but are not consumed as much as gasoline.
- Engines that operate on diesel rather than gasoline work slightly differently, with compression providing energy to start the reaction, rather than a spark.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		**NAVIGATE** Orient students to where we left off last class and identify where our initial consensus model has gaps.	A-B	Lesson 1 exit ticket, initial consensus model
2	10 min		**CONSIDER HOW FUEL COMBUSTION MAKES VEHICLES MOVE** Have students examine information about personal vehicle engines using *Gasoline Engine Operation*. Trace the movement of matter (fuel) to think through the mechanism that results in the movement of the vehicle.	C-E	*Gasoline Engine Operation*, initial consensus model
3	5 min		**EXAMINE INTERNAL COMPONENTS OF THE ENGINE** Examine the cylinder system to identify the connections between the engine and the wheels. Have students use this new information to revise their explanations.	F-I	*Gasoline Engine Operation*
4	15 min		**APPLY M-E-F THINKING TO GASOLINE VEHICLES** Have students turn and talk with a partner to revise their initial models. Lead a class discussion and revise the class consensus model using M-E-F thinking.	J	*Gasoline Engine Operation*, *Initial Fuel Model*, M-E-F poster, initial consensus model, chart paper markers
5	7 min		**TEST IDEAS BY BURNING FUEL** Review safety guidelines with students. Conduct the Fire Combustion Demonstration 1. Have students record evidence of matter changes and energy transfers during the demonstration.	K-L	Fire Combustion Demonstration 1
					End of day 1
6	3 min		**NAVIGATE** Have students turn and talk with a partner about the matter changes and energy transfers they observed last class.	M	
7	15 min		**TEST IDEAS BY BURNING FUEL AGAIN** Burn a small amount of ethanol to generate evidence of inputs and outputs of a combustion reaction.	N-P	Fire Combustion Demonstrations 2 & 3
8	15 min		**EXPLAIN CHANGES IN MATTER DURING COMBUSTION REACTIONS** Lead a class discussion of the investigation results. Compare the chemical equation for combustion of alcohol to gasoline and develop a definition for *combustion reactions*. Have students balance other combustion reactions.	Q-W	*Balancing Fuel Equations*, individual whiteboard, dry erase marker, Fuel Data Cards from Lesson 1

Part	Duration		Summary	Slide	Materials
9	12 min		**EXPLAIN ENERGY TRANSFERS AND FORCES DURING COMBUSTION REACTIONS IN VEHICLES** Lead a discussion to develop a model to show energy transfers within the cylinder system during a combustion reaction. Conduct the Syringe Piston Demonstration to develop ideas around force interactions, or pressure, inside the cylinder.	X-AA	*Gasoline Engine Operation*, *Balancing Fuel Equations*, chart paper, chart paper markers, M-E-F poster, Syringe Piston Demonstration
					End of day 2
10	5 min		**NAVIGATE** Have students turn and talk with a partner to make predictions about how changes in energy affect pressure.	BB	"M-E-F Model of the Engine Cylinder" poster
11	7 min		**REVISE MODELS TO INCORPORATE NEW UNDERSTANDINGS** Have students use the previous demonstrations and discussions to revise their models.	CC	*Initial Fuel Model*, *Gasoline Engine Operation*, *Balancing Fuel Equations*, *Revised Gasoline Model*, "M-E-F Model of the Engine Cylinder" poster, initial consensus model, M-E-F poster
12	10 min		**ANALYZE CHARACTERISTICS OF OTHER FUELS** Have students analyze data using CODAP to identify patterns in characteristics of other used fuels.	DD-FF	*Fuel Data Comparisons*, internet-connected device, https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FnRytaIM9fBnZ9n5aPE1m%2Ffile.json, Gasoline and Diesel Fuel Data Cards (optional)
13	8 min		**BUILDING UNDERSTANDINGS DISCUSSION ABOUT FUEL COMPARISON** Facilitate a Building Understandings Discussion about the patterns seen in the fuel data.	GG	*Fuel Data Comparisons*
14	10 min		**ANALYZE CHARACTERISTICS OF OTHER ENGINES** Have students compare the cylinder systems of gasoline and diesel fuel engines. Conduct the Fire Syringe Demonstration.	HH-II	*Diesel Engine Operation*, *Gasoline Engine Operation*, Gasoline and Diesel Fuel Data Cards (optional), Fire Syringe Demonstration
15	5 min		**NAVIGATE** Have students develop their Progress Trackers. Navigate to the next lesson.	JJ-KK	*Progress Tracker*
					End of day 3

Lesson 2 • Materials List

	per student	per group	per class
Fire Combustion Demonstration 1 materials	• science notebook • sanitized indirectly vented chemical splash goggles • non-latex apron		• tea candle holder (with no candle) • 1000 mL glass beaker • 50 mL ethanol or isopropyl alcohol • Piezo igniter
Fire Combustion Demonstrations 2 & 3 materials	• science notebook • sanitized indirectly vented chemical splash goggles • non-latex apron		• IR thermometer • 3 tea candle holders • 1000 mL glass beaker • 100 mL ethanol or isopropyl alcohol • 25 mL bromothymol blue (BTB) • 2 small clear plastic cups or small petri dishes • Piezo igniter • water • sticky tack (optional)
Syringe Piston Demonstration materials	• sanitized indirectly vented chemical splash goggles • non-latex apron		• large plastic syringe with cap • 1000 mL glass beaker • hot water
Fire Syringe Demonstration materials	• sanitized indirectly vented chemical splash goggles • non-latex apron		• fire syringe • small piece of cotton • https://youtu.be/kiYfaaibWL0
Lesson materials	• science notebook • Lesson 1 exit ticket • *Gasoline Engine Operation* • *Initial Fuel Model* • *Balancing Fuel Equations* • *Revised Gasoline Model* • *Fuel Data Comparisons* • *Diesel Engine Operation* • *Progress Tracker*	• individual whiteboard • dry erase marker • Fuel Data Cards from Lesson 1 • internet-connected device • https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FnRytaIM9fBnZ9n5aPE1m%2Ffile.json • Gasoline and Diesel Fuel Data Cards (optional)	• initial consensus model • M-E-F poster • chart paper markers • chart paper • "M-E-F Model of the Engine Cylinder" poster

Materials preparation (45 minutes)

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

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

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

Have a piece of chart paper ready for modeling energy and forces in the cylinder system on day 2. You will label this as "M-E-F Model of the Engine Cylinder" after completing the model.

Have the M-E-F poster and initial consensus model from Lesson 1 ready for display.

Before making copies of *Progress Tracker*, finish preparing the file for students by adding the criteria and constraints that were generated in Lesson 1 to the table on the first page. Leave space for students to add criteria and constraints throughout the unit.

Familiarize yourself with CODAP, at https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FnRytaIM9fBnZ9n5aPE1m%2Ffile.json. This video may help: https://youtu.be/pRD2strLCws.

See *L2 Demonstrations Summary* for an overview of the demonstrations in this lesson and links to videos.

General safety protocols for demonstrations and hands-on activities:
Prior to doing any of the demonstrations, read through the "safe handling of alcohol in the laboratory" and be certain to follow all safety protocols noted: https://www.nsta.org/safer-handling-alcohol-laboratory.

Noted protocols needing special attention include the following:

- Conduct a hazards analysis and risk assessment of the use of alcohol and review safety action to be taken before doing any lab investigation or demonstration. Prepare a list of the significant hazards in the procedure and identify the controls necessary to minimize them. The procedure, hazards analysis, and risk assessment should be reviewed and approved by the Chemical Hygiene Officer (or designee) as indicated by the Chemical Hygiene Plan.
- Demonstrations are to be conducted under a fume hood to capture and prevent any flammable and/or combustible concentrations of vapors from reaching any source of ignition.
- If a fume hood is not available during a demonstration, place an impact-resistant barrier between the experiment and students. Also ensure that students or other observers are more than 10 feet (~3 meters) away (NFPA 45). The safety shield should be made of impact-resistant plastic or tempered glass and be 24" high and extend 12" beyond the hazard in both directions. All individuals (adults and students) in the room should wear the appropriate safety goggles during the demonstration. In the absence of a permanent fume hood, a portable fume hood that is rated for alcohol use can be used.
- Make sure all laboratory occupants are wearing sanitized indirectly vented chemical splash goggles and non-latex aprons during the demonstration set-up, hands-on and takedown portions.
- Know the location of the A-B-C fire extinguisher, fire blanket, fire alarm, eyewash, and shower and be able to reach them within 10 seconds. Teachers should receive annual training so that they know how to use each of these items. If district policy prohibits the use of a fire extinguisher, in the event of fire, evacuate the room, close the door, and pull the fire alarm.
- Review the SDS before using alcohol and make students aware of all hazards.
- Practice the laboratory or demonstration before conducting it with students.

Day 1: Fire Combustion Demonstration 1

- **Group size:** Whole-class
- **Setup:** Gather the materials for the demonstration. Try the demonstration on your own, so you are comfortable performing it in front of students.
- **Notes for during the lab:** Ensure that the flame burns for 10-15 seconds before it is covered with the beaker and extinguished. The beaker must be large enough to fit over two of the tea candle holders.
- **Safety:** In addition to the standard safety considerations, read through the safe handling of ethanol in the laboratory guidance: https://www.nsta.org/safer-handling-alcohol-laboratory. Operate the Piezo igniter only as directed.
- **Disposal:** All non-consumable materials are reusable as long as they are in good condition.
- **Storage:** Store extra ethanol in a flammable safety cabinet.

Day 2: Fire Combustion Demonstrations 2 & 3

- **Group size:** Whole-class
- **Setup:** Gather the materials for the demonstration. Test that both demonstrations work according to the directions found in this teacher guide.

- **Notes for during the lab:** Prepare the bromothymol blue (BTB) according to directions on the label. Allow the BTB to "acclimate" overnight. Ensure that the IR thermometer is functioning correctly.
- **Safety:** In addition to the standard safety considerations, read through the safe handling of ethanol in the laboratory guidance: https://www.nsta.org/safer-handling-alcohol-laboratory. Operate the Piezo igniter only as directed.
- **Disposal:** All non-consumable materials are reusable as long as they are in good condition.
- **Storage:** Store extra ethanol in a flammable safety cabinet.

Day 2: Syringe Piston Demonstration

- **Group size:** Whole-class
- **Setup:** Gather materials for the demonstration. The syringe cap is stored in a groove in the plunger of the syringe.
- **Notes for during the lab:** Prepare a container of hot water that is able to mostly submerge the large syringe (100 mL works well). A hot plate or electric kettle works well if you do not have hot tap water. Water does not need to be boiling. Make sure the syringe is capped so that air cannot escape, and hold its sides so that the top can move freely.
- **Safety:** Follow standard safety considerations.
- **Disposal:** Water may be reused across sections and emptied into the sink or used to water plants when cooled.
- **Storage:** Be sure to store the syringe with its cap.

Day 3: Fire Syringe Demonstration

- **Group size:** Whole-class
- **Setup:** Gather the materials for the demonstration. Test the fire syringe prior to using it with students.
- **Notes for during the lab:** Make sure you push the plunger straight down to avoid damaging the fire syringe device. Only a very small amount of cotton is needed.
- **Safety:** Follow standard safety considerations.
- **Disposal:** Be sure to clean out the device.
- **Storage:** Do not store flammable materials in the device.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.B.1 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.

Crossout explanation: Students investigated reaction rates in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. They will dig into ideas of energy storage in fields between atoms in Lesson 4, and examine changes in net bond energy in Lessons 6 and 7.

While not assessed, a second disciplinary core idea will be helpful for student sensemaking:

- **PS3.A.2 Definitions of Energy:** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

This lesson has many investigative phenomena with important coherence-related reasons for each:

1. Diagrams of a vehicle and a cylinder and piston in a gasoline engine show how different structures in a vehicle work together to allow it to move.
2. Ethanol is ignited and given adequate time to burn, so students can initially consider energy transfer into and out of the reaction.
3. Ethanol is ignited without adequate time to burn, establishing that air (likely oxygen) is required.
4. Ethanol is ignited in the presence of bromothymol blue to establish that carbon dioxide is given off, at which point the class can finally use a chemical equation because we agree on the reactants and products. The temperature is also taken with an IR thermometer at this time to allow for the energy transfer to be more thoroughly analyzed.
5. A closed syringe expanding when placed in warm water shows that forces from higher-temperature gas can be applied to a piston.
6. The fire syringe establishes that combustion can occur without a spark and prompts us to consider the collisions of molecules.

While not explicitly tied to assessment, students use *structure and function* thinking at the macroscopic scale to help them explain how structures work together in a vehicle (CCC: 6.1). This builds on the molecular use of *structure and function* thinking developed in *Space Survival Unit*.

This lesson is students' first opportunity in the chemistry course to apply M-E-F thinking in the context of a mechanical system, but students can build on prior use of *energy and matter* in *Polar Ice Unit* and *Electrostatics Unit* (CCC: 5.2). Students do this largely in the context of *developing and using models* of the reaction in the cylinder at the particle level, which builds on work done in *Polar Ice Unit* and *Oysters Unit* (SEP: 2.3). Throughout the first and second day, students will gain evidence from a variety of sources that will allow them to construct and revise an explanation for how gasoline engines generate the forces needed for vehicle motion (SEP: 6.2).

During day 3, students will use their gasoline engine sensemaking to explore and analyze a multivariable data set using the data analysis tool, CODAP. During this data comparison, students will be able to identify fuels that exhibit key design features needed in next-generation fuels: high energy released and lower carbon emissions (SEP: 4.6). Fuels that meet these key design features will be uncovered by finding patterns of performance among the various fuels that made sense on day 1 (CCC: 1.3). The patterns in the data should motivate students to want to explore diesel because it is currently being used, has more energy than gasoline, and produces less carbon emissions.

In this lesson, students will co-construct definitions for the following terms, which they should add to their Personal Glossaries: *combustion reaction* and *pressure*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students will not be calculating changes in energy in this lesson. That will occur in Lesson 7. Between now and then, students will figure out that:

- energy is inputted in diesel engines due to a drop in volume, which results in an increase in pressure and temperature (Lesson 3);
- energy transfers must be into the field for bonds to break (Lesson 4);
- energy is transferred out of a field when bonds are formed (Lesson 5);
- energy transfer can be predicted by considering both bonds broken and bonds formed (Lesson 6); and
- bond energy and net energy transfer can be quantified (Lesson 7).

Students briefly consider fuel properties as they relate to function when they consider fuel data. However, students' ideas about material properties and function are not assessed as this was emphasized in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

LEARNING PLAN for LESSON 2

1 · NAVIGATE

8 min

MATERIALS: science notebook, Lesson 1 exit ticket, initial consensus model

Ask students where we left off last class. Display **slide A.** Orient students to how they were feeling about fuels and climate change when they completed the exit ticket. Ask for volunteers to share the thoughts they had about our current fuel uses, and have other students indicate if they had similar feelings. ✱ This could be through a show of hands, thumbs up, nods, or other nonverbal responses. Point out to the class that many students share the same feelings.

Suggested prompt	Sample student response
How are you feeling about transportation and climate change after last class?	Accept all responses.
Of the fuels we examined, which seemed to be having the biggest impact on climate change?	All the ones that release CO_2. Gasoline and to a lesser extent diesel, because they release CO_2 and are most heavily used, especially in personal vehicles.
What do these differences make you wonder about the prevalent use of gasoline in personal vehicles?	Why aren't all fuels used in personal vehicles? Why do we use gasoline so much when it releases CO_2? Why are some fuels used in lots of things while some only work in a few?

Think about what is missing in our model. Display **slide B.** Spend a few minutes brainstorming what additional information we need to figure out in order to start developing solutions. Give students a minute to look back at the initial consensus model from Lesson 1, through the lens of what is missing.

ADDITIONAL GUIDANCE

It is helpful to center students as agents over the class consensus model. Have students lead the way in uncovering questions and missing components/interactions within their model.

Suggested prompt	Sample student response
What is missing from our current model?	We didn't say much about how the forces moving the wheels were created. We aren't sure how the fuel actually moves the car. We didn't show what was happening inside the engine.

✱ ATTENDING TO EQUITY

Discussions that focus on climate change can cause anxiety in students. It is important to acknowledge that these topics can be stressful to think about or discuss and to validate those feelings when they come up for students. It is also important to discuss with students how to support each other in class and what strategies to use when these feelings come up. See ideas for additional support in Lesson 1.

Suggested prompt	Sample student response
What do we need to know to develop solutions other than gasoline?	We need to figure out how engines work. We need to figure out what forces are acting on a vehicle. Maybe we should try to see what is happening inside an engine. We should understand how gasoline makes a personal vehicle move.

Highlight personal vehicle engines. Summarize the areas students identified as ideas we need to understand for next steps. Highlight those that point out the need to develop our understanding around vehicle engines.

2 · CONSIDER HOW FUEL COMBUSTION MAKES VEHICLES MOVE

10 min

MATERIALS: *Gasoline Engine Operation*, initial consensus model

Direct students' attention back to the initial consensus model. Display **slide C**. Direct students to talk to a partner about the three questions before asking, "Who can help us answer these questions as a whole class with something they heard their partner say?"

Suggested prompt	Sample student response
What components of the vehicle must work together to make it move?	The engine. The gas pedals. The wheels.
What other components may be important to help move fuel to and from the engine?	The exhaust pipe? The fuel line that brings fuel to the engine.
What other components may be important to help transfer energy from the engine to the wheels?	Accept all answers.

Identify a possible mechanism to account for vehicle movement. Distribute *Gasoline Engine Operation* and display **slide D**. Say, *Now that we have brainstormed some components of our model, let's add them, along with some other essential components of a vehicle.* Next, have students begin to consider how these components interact to create vehicle motion. Direct the students to develop their ideas in groups and refer them to the Initial Mechanism of Movement prompts in *Gasoline Engine Operation* to help guide their group discussion.✱

After four minutes, have groups share their ideas. Record any new ideas or questions on the initial consensus model.

Consider gaps in our explanations. Display **slide E**. Say, *We have some uncertainty about the connection between the engine and the wheels of the vehicle. Turn and talk with a partner about the prompt on the slide.* After a minute, ask for a few volunteers to share what they heard from their partners. Look for students to suggest that we need to look inside the engine.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

For students to begin to think about the chemical reaction, combustion, occurring inside a vehicle engine to produce movement, they need to consider the overall structure of the vehicle. By first *looking at the overall structure* of the vehicle, students can *infer how individual components function* to transfer fuel and energy through the vehicle to result in movement. In the next step of the lesson plan, students continue this line of thinking by examining a *smaller component* of the engine, the cylinder system, which is the location of the combustion reaction and is *responsible for starting the energy transfers* through the vehicle, resulting in movement. (CCC: 6.1)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students share explanations based on evidence that identify the connections between various components of a vehicle to explain how they work together to make the vehicle move. (SEP: 6.2; CCC: 6.1)

What to do: If students do not specifically identify the connections between components, have them refer back to *Gasoline Engine Operation* and point out areas where the components connect. At this point students are verbally sharing their explanations, though some students may not share during the whole-class discussion. Encourage these students to share their ideas as they turn and talk with a partner.

Building toward 2.A.1 Construct and revise an explanation based on models showing the structure and function of vehicle components that explains how chemical processes release energy, allowing the vehicle to move. (SEP: 6.2; DCI: PS1.B.1; CCC: 6.1)

3 · EXAMINE INTERNAL COMPONENTS OF THE ENGINE

5 min

MATERIALS: science notebook, *Gasoline Engine Operation*

Examine internal components of the engine cylinder. Say, *It may help us think about what is happening inside the engine if we can see inside it.* Display **slide F** and have students look at the image of the cylinder structure inside the engine, on page 2 of *Gasoline Engine Operation*. Say, *This is a cross section of a portion of a vehicle engine.* Point out that the image shows three cylinders and pistons in the engine.✱

Suggested prompt	Sample student response
What do you notice?	The pistons look like they move up and down. There is something at the bottom of the piston that also looks like it moves; maybe it connects to the wheels.
What do you wonder?	Where does the fuel go? Is there fuel even in there? What happens when the engine is running?

Say, *I have another view of the engine cylinder that may help answer some of our wonderings.* Display **slide G**.

Suggested prompt	Sample student response
How does this new view help answer some of our wonderings?	It shows that fuel goes into the cylinder.
What new things do you notice?	I noticed that there is an air intake valve, so that means that air must be in there too. There is a spark plug. It looks like the piston rotates.

✱ ATTENDING TO EQUITY

Many students have out-of-school identities and interests in automotives, even students you might not expect. In high school, many students have to know some facts about engines to pass their drivers' tests. If time allows, you can ask students who know the rest of the "movement story" of vehicles (drivetrain, axles, transmission) to share how the vehicle begins to move after the explosion in the cylinders.

Suggested prompt	Sample student response
What new things do you wonder?	What does the spark plug do? What do the valves do? What does it look like when the engine is running?

Observe the piston in motion. Say, *It sounds like we want to look at the cylinder and piston as the engine is running. I have some short videos that we can watch that might help us.* Display **slide H**. Have students record in their science notebooks what they notice and wonder as they watch the video and animation. Tell students to follow along with the animation in the Piston Stroke table on *Gasoline Engine Operation*.

Revise explanations for how the components of a vehicle work together to cause movement. Display **slide I**. Say, *Now that we have an idea of how the different components of the engine work, let's revise our explanations.* Have students stop and add to their models on page 1 of *Gasoline Engine Operation* using the two prompts on the slide. If you have time, ask for a few volunteers to share their responses. See the suggested prompt and sample student response box below.

Suggested prompt	Sample student response
What is happening between the fuel tank and the wheels?	The fuel comes in from the fuel tank and then explodes here. The energy from the explosion moves the piston and that moves the wheels, or it moves something else connected to the wheels.
How do these parts work together to make a vehicle move?	The fuel comes from the fuel tank into the engine. There is a spark that probably ignites the fuel. After the spark, what's in the engine changes color and leaves. The thing at the bottom that is spinning might turn the axles to make the wheels move.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students share explanations based on evidence that identify the connections between various components of a vehicle to explain how they work together to make the vehicle move. (SEP: 6.2; CCC: 6.1)
- Students state that the energy released from burning fuel causes the piston to move, which ultimately causes the wheels to move. (DCI: PS1.B.1; CCC: 6.1)

What to do: If students do not connect the release of energy through burning to the movement in the vehicle, consider showing them the animations on **slide H** an additional time. Highlight the spark, or burning, on both animations. You may consider having students revise their explanations after observing Fire Combustion Demonstration 1 (**slide L**). If desired, you may collect these explanations and provide quick notes. Bring up the question of whether this same explanation would apply to other fuels. Students will have an opportunity to revise their explanations in a full model on day 3 and then explore fuels other than gasoline.

Building toward 2.A.2 Construct and revise an explanation based on models showing the structure and function of vehicle components that explains how chemical processes release energy, allowing the vehicle to move. (SEP: 6.2; DCI: PS1.B.1; CCC: 6.1)

4 · APPLY M-E-F THINKING TO GASOLINE VEHICLES

15 min

MATERIALS: science notebook, *Gasoline Engine Operation*, *Initial Fuel Model*, M-E-F poster, initial consensus model, chart paper markers

Consider changes in matter, energy, and forces. Say, *Let's use matter-energy-forces (M-E-F) thinking to try to revise our initial models. Work with a partner to update your initial models on Initial Fuel Model. As you work, start with matter, then energy, then forces.* Have the M-E-F poster from *Electrostatics Unit* and the initial consensus model from Lesson 1 visible.

Display **slide J**. Give students five minutes to use the prompts on the slide with their partner to update their initial models on *Initial Fuel Model*.

After five minutes, discuss the prompts as a whole class. As students share where they have identified areas of matter changes, energy transfers, and force interactions on their initial models, add these to the class consensus model. Use different-color markers for each interaction: matter, energy, and forces.

ADDITIONAL GUIDANCE

During the next several portions of the lesson, students will evaluate and revise their models using M-E-F thinking in light of new investigative data. To help students organize their thoughts, investigative data will help them focus on one aspect of M-E-F thinking. In the three Fire Combustion Demonstrations, students will consider matter changes and energy transfers during the combustion reaction. In the Syringe Piston Demonstration, students will consider force interactions. They will tie in energy transfers to forces thinking during the Fire Syringe Demonstration on day 3.

Suggested prompt	Sample student response
What matter changes are occurring inside the cylinder system?	Fuel goes in, something happens, then exhaust leaves the engine. A chemical reaction happens when the fuel explodes. Different things enter and exit the cylinder as the piston moves up and down.
What evidence do you see of energy transfer into and out of the cylinder system?	The piston is moving, so it's transferring energy or something is transferring energy to it. There is a spark. The bottom of the piston turns something, so it's transferring energy. We know engines heat up, so that is energy being released.
Where are forces being applied, and how?	The piston pushes on the fuel and on the engine. The fuel molecules bounce around and hit stuff and push on the cylinder and the piston. When the piston moves it applies a force to other things that move. And then eventually the wheels move.

After the discussion, give students two minutes to add any new ideas to their initial models. Summarize the ideas students have shared about M-E-F thinking on the class consensus model. Highlight where they have had some questions about matter changes and energy transfers, and suggest that we start to answer those first.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students develop and revise models to incorporate evidence from models and investigations to track and identify changes in matter and energy transfers. (SEP: 2.3; CCC: 5.2)

What to do: Ensure that students take some time to check over their individual revision and update it based on class discussions.

Building toward 2.B.1 Develop, revise, and use models based on evidence to identify relationships between changes in matter and energy transfers that take place in a vehicle as a result of the combustion of fuel. (SEP: 2.3; DCI: PS1.B.1; CCC: 5.2)

5 · TEST IDEAS BY BURNING FUEL

7 min

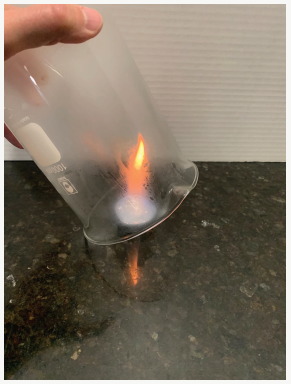
MATERIALS: Fire Combustion Demonstration 1

Test what happens when we add a spark to a fuel in a clear cylinder. Say, *Let's see if we can figure out the connection between matter changes and energy transfers. The demonstration I will do does have some safety considerations.* Review the safety information on **slide K** and remind students they need to stay six feet away from flames while the demonstration is happening.

✱ ATTENDING TO EQUITY

Display **slide L**. Show students the equipment available to test the matter changes and energy transfers in the cylinder system of the engine. Say, *The image on the slide is a sample of the equipment we can use to simulate the matter changes and energy transfers inside the cylinder. How could we use this equipment to gather data to identify matter changes and energy transfers?* Accept all student suggestions and encourage them to identify what the tea candle holder will represent in the cylinder system. Finish the discussion by asking students to brainstorm some ways they might observe an energy transfer.✱

Instruct students to record data around matter changes and evidence of energy transfers in their science notebooks as you complete the Fire Combustion Demonstration 1. Set up the fuel in the tea candle holder and partially cover it with a beaker by holding the beaker upside down at an angle to allow access to the fuel. Use the Piezo igniter to ignite the fuel in the tea candle holder and let it burn for 2-3 seconds before covering it. The fire will go out fairly quickly after being covered.



Ask students what evidence they noticed of energy transfer. Listen for:

- *The fuel burns.*
- *We saw light from the igniter and the flame.*
- *If we put our hands near the beaker it would feel hot.*

ALTERNATE ACTIVITY

If you have time, consider having students revise the explanations they first developed (verbally) on **slides D-E** and revised (written) on **slide I**. Students should add a *mechanism explaining* how a chemical process leads to vehicle movement.

Universal Design for Learning: Even though the investigation is already designed to encourage safety, giving students an opportunity to think about its design helps support students' use of *action and expression* by giving them an opportunity to engage with planning and strategy. Encourage students to think about how the investigation setup impacts the types of data they can collect to try to make progress on their questions around matter changes and energy transfers.

End of day 1

6 · NAVIGATE

3 min

MATERIALS: science notebook

Navigate. Display **slide M**. Have students turn and talk with a partner about the prompts on the slide. Then ask for volunteers to share out. Listen for students to suggest:

- *The molecules are made of mostly carbons and hydrogens.*
- *Molecules break apart.*
- *Maybe atoms form new molecules.*

Highlight any ideas around matter changes that would benefit from a second round of investigation.

7 · TEST IDEAS BY BURNING FUEL AGAIN

15 min

MATERIALS: Fire Combustion Demonstrations 2 & 3

Discuss ideas around matter changes during the reaction. Say, *Let's take a moment to try to connect the matter changes in the demonstration to our ideas about the gasoline powered vehicle.* Display **slide N** and give students one minute to turn and talk with a partner before discussing the prompts as a class.

Suggested prompts	Sample student responses	Follow-up questions
What were the matter inputs and outputs when we burned the ethanol?	Fuel, or ethanol. There needs to be air present. Carbon dioxide is an output.	*What is your evidence for this?*
What about in a gasoline-powered vehicle?	Gasoline and air are inputs. Carbon dioxide is an output.	*What is your evidence for this?*
What similarities do you notice between ethanol and gasoline?	It's mostly carbon and hydrogen atoms. Carbon atoms seem to be at the center of the molecule.	*What do we remember about carbon and hydrogen from previous units?*

ADDITIONAL GUIDANCE

In addition to fuel and carbon dioxide, students may say that the air or oxygen is an input and water vapor is an output. If they do not, that is fine, as students will see evidence for those substances during the demonstration. If students do mention oxygen and water vapor, follow up by asking what evidence they have or can look for to support their ideas.

Begin to highlight similarities in the inputs and outputs of the burning fuel and engine reactions. The goal of this is to start to prime students for defining *combustion reactions* later in the lesson.

Conduct Fire Combustion Demonstration 2. Say, *It seems like we have some ideas about the matter inputs and outputs from the demonstration. Let's watch this reaction again and see if we can identify any other matter inputs or outputs.* Conduct the Fire Combustion Demonstration 2 using the same setup as for the Fire Combustion Demonstration 1, but this time cover the burning ethanol with the beaker as soon as it is lit with the Piezo igniter. Students should notice the flame going out very quickly.

Discuss the results. Express confusion or disappointment in how quickly the flame went out. Display **slide O**.

Suggested prompt	Sample student response
What made the flame go out so quickly?	You put the cover on too fast. We need air for something to burn. There wasn't enough air or oxygen in the beaker.
What does this tell us about the matter inputs and outputs?	That air or oxygen is also an input, not just fuel. Carbon dioxide is still produced as long as the fuel is burning.

Suggested prompt	Sample student response
How could we collect evidence of these inputs and outputs?	We can burn the fuel both covered and uncovered and see the difference. The flame should burn longer if it is uncovered because there will be more air. We can use BTB or an indicator to test for carbon dioxide. We can use a thermometer to measure temperature change.

ADDITIONAL GUIDANCE

If students are unsure if lack of oxygen is the cause of the flame going out because some might be getting in the sides, put sticky tack around the base of the beaker so there is a tight seal when it is placed over the flame.

If students do not suggest using BTB, prompt them to think about indicators we have used to test for the presence of carbon dioxide in past units. Students used BTB in *Oysters Unit*.

Conduct Fire Combustion Demonstration 3. Display **slide P**. Point out that in this investigation setup we are adding BTB and we have an IR thermometer available.

Suggested prompt	Sample student response
How does the addition of BTB help us make sense of matter changes taking place during this reaction?	BTB can tell us if the reaction is producing carbon dioxide.
How does the addition of the IR thermometer help us make sense of energy transfers taking place during this reaction?	The IR thermometer can measure temperature changes.

Tell students to record data from the demonstration in their science notebooks.

Complete Fire Combustion Demonstration 3 using the steps below.
1. Add more ethanol to the tea candle holder you used for the Fire Combustion Demonstration 2.
2. Add several drops of BTB to two other tea candle holders with water in them.
3. Place one tea candle holder with BTB in it next to the tea candle holder that contains the ethanol. Leave the other BTB sample off to the side as a control.
4. Place one tea candle holder with BTB in it next to the tea candle holder that contains the ethanol. Leave the other BTB sample off to the side as a control.
5. Cover the tea candle holders containing BTB and ethanol. Have a student use the IR thermometer to take the temperature of the beaker. Record this on the board.
6. Lift up the beaker and use the Piezo igniter to ignite the alcohol. Partially cover the two tea candle holders. This will help to collect carbon dioxide, which will be needed to change the color of the BTB.
7. After about a minute of burning, cover the tea candle holders with the beaker. While waiting to see if the BTB color changes, discuss whether this helps us confirm that oxygen is needed for something to burn.



8. Have a student use the IR thermometer to take the temperature a second time. Record this on the board.
9. Invite students to come up to the demonstration to record additional data. Students should be able to see condensation on the inside of the beaker.
10. After enough time has passed for the BTB to change color, pour both containers of BTB into the clear plastic cups so that students can compare the colors. The BTB that was next to the burning fuel should be a green or yellow color, and the BTB that sat out should still be blue.

ALTERNATE ACTIVITY

BTB can be combined with the ethanol in a watch glass; it will be more green than the blue color students see when BTB is added to tap water. There will be an immediate color change to yellow when the ethanol burns, but the color change is less striking. If using this method, it may be helpful to have a second reference BTB receptacle so that students can compare the colors before and after the reaction.

The recommended method is described above, but this alternative may save a bit of time and will work if you are missing a fuel container like the tea candle holders.

8 · EXPLAIN CHANGES IN MATTER DURING COMBUSTION REACTIONS

15 min

MATERIALS: science notebook, *Balancing Fuel Equations*, individual whiteboard, dry erase marker, Fuel Data Cards from Lesson 1

Discuss investigation results. Display **slide Q**. Say, *Let's spend a moment thinking about matter inputs and outputs in the ethanol burning demonstrations in terms of reactants and products of a chemical reaction.*

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Suggested prompt	Sample student response
What reactants did we use?	Ethanol Oxygen
What products were formed as a result of the chemical reaction?	Carbon dioxide Water
What else was essential for the reaction to occur?	A spark Energy input
What might be happening to the atoms in the reactant molecules during the reaction?	Atoms are separating and forming new molecules. Bonds are breaking and reforming. Energy is being released.

ADDITIONAL GUIDANCE

If you used isopropyl alcohol instead of ethanol in the demonstrations, it may benefit students to look at the Fuel Data Cards from Lesson 1 to connect the chemical formula of isopropyl alcohol to that of ethanol and other carbon-based fuels. Dimethyl ether has the same number of carbons, hydrogens, and oxygens as ethanol. While the two chemicals are isomers, it is not important to explain the difference between them to students. Note that the chemical formula given on **slide R** is of ethanol.

Identify conditions needed for the reaction to continue. Say, *It was kind of disappointing when the reaction was short on oxygen and went out. What do you think would happen if there is not enough oxygen available to an engine?* Students should say that the fuel will not burn, or not all of the fuel will burn. Say, *It would be really disappointing if your engine was not burning your fuel. You would not get as much energy out of the fuel you buy.* Display **slide R**.

Suggested prompt	Sample student response
How do we make sure all of the fuel burns completely in the engine?	It needs to have enough oxygen present so the reaction can continue.
What information do we need to know to make sure all of the fuel burns completely?	If we know how much fuel we have, we can figure out how much oxygen is needed. A balanced chemical equation will tell us this.
What else could this tell us?	How much CO_2 is produced when a fuel burns.

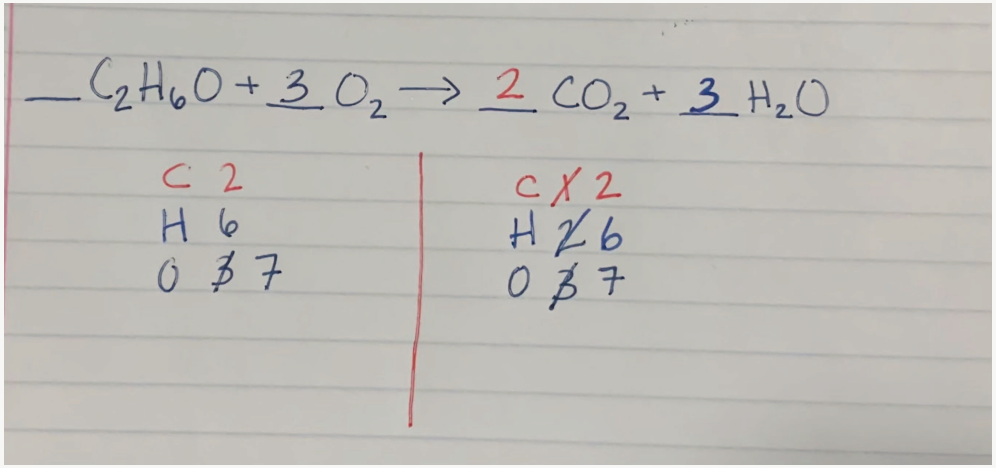
Balance the equation for burning ethanol.✱ Say, *We know the reactants—ethanol and oxygen—and the products—carbon dioxide and water vapor—of burning ethanol. Now, let's balance the chemical equation for this reaction.* Display **slide S**. Distribute *Balancing Fuel Equations* to students. Write out the equation for the combustion of ethanol on the board and balance it as a class, adding coefficients and keeping track of numbers of atoms.

Students will work to balance three combustion equations. Different levels of support are provided to help them *apply algebraic techniques* as they work to balance these equations. The first two are done as a whole class and the third is done in a small group. If students are proficient in balancing chemical equations, they could balance the second equation individually and then share with the whole class. (SEP: 5.3)

ADDITIONAL GUIDANCE

Alternate: *Remove scaffolding.* The tables provided for students to balance chemical equations on *Balancing Fuel Equations* contain additional rows to support students in keeping track of numbers of atoms. If your students do not need these additional scaffolds, remove those rows and provide empty space on the handout.

See the image for the balanced chemical equation for burning ethanol.



Trace matter and energy in the vehicle system. Say, *We have agreed that we can use ethanol as a stand-in for a carbon-based fuel. So, now let's tie this back to what is happening with gasoline in a vehicle. Let's map this equation to our engine and fuel system.*

Display **slide T.** Ask, *What matter inputs, or reactants, enter the vehicle system? Where?* Look for students to identify that fuel, or gasoline, and oxygen are the inputs. They should identify that these substances enter the fuel tank and engine, respectively. Have students add these to the image on *Balancing Fuel Equations*.

Ask, *What matter outputs, or products, exit the vehicle system? Where?* Look for students to identify that carbon dioxide and water are the outputs. They should identify that these substances exit from the exhaust tailpipe. Have students add these to the image on *Balancing Fuel Equations*.

Display **slide U**. Ask, *Since the fuel we are using is gasoline, can someone remind us of the chemical formula for it?* Students should say, C_8H_{18}. Tell students to add that chemical formula to the table on *Balancing Fuel Equations*. Then continue, *Now let's see if we can figure out the exact ratios of these substances.* Work together to balance the chemical equation for burning gasoline. If students feel confident, they could do this individually and you could have a few volunteers come to the board to talk through their process. Before starting, remind students that they should expect bigger coefficients than they have worked with in the past.

The balanced chemical equation for burning gasoline is: $2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$

ADDITIONAL GUIDANCE

Slide U contains an image showing the matter inputs and outputs in a vehicle. This helps to support student engagement with *representation* by removing barriers that text alone could present. Giving alternative displays helps to increase ways for students to perceive the information and supports them to ensure they can check their responses on *Balancing Fuel Equations*.

Add combustion reaction to Personal Glossaries. Display **slide V**. Ask, *What do both of these burning reactions have in common?* Look for students to say they both have oxygen as a reactant and carbon dioxide and water as products.

Say, *In both of these reactions we also saw fire. Another word we sometimes use to say that something is on fire is* combust. *Chemists classify these burning reactions that require oxygen and produce carbon dioxide and water as combustion reactions. Take a moment to add* combustion reaction *to your Personal Glossary.*

Balance another chemical equation for burning fuel. Organize students into small groups and display **slide W**. Distribute a whiteboard and dry erase marker to each group. Tell groups to choose one of the carbon-based fuels on the slide. As groups work, circulate around the room and assist as needed. If time allows it, work as a whole class to workshop any of the chemical reactions.

Propane: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$
Butane: $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$
Kerosene or diesel: $2C_{12}H_{26} + 37O_2 \rightarrow 24CO_2 + 26H_2O$

ADDITIONAL GUIDANCE

Allow students to choose which fuel combustion equation they want to balance based on their comfort level with balancing equations. This choice, coupled with the class example and the model of the vehicle and engine, is intended to increase students' *engagement* by making the task accessible to all students, thereby reducing barriers to achieving the 3D lesson-level performance expectation.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students develop a model to track matter flows in combustion reactions by balancing chemical equations. (SEP: 2.3; CCC: 5.2)
- Students determine that combustion reactions result in the rearrangements of reactant molecules into two possible products. (DCI: PS1.B.1)

What to do: Students have previously balanced equations and should be reasonably proficient, or at least clear that they are showing matter conservation and flows. They should also be comfortable with the products from each reaction, given evidence from earlier in the lesson. However, this is their first experience with combustion reactions and they may be surprised by the iteration and adjustments required in balancing given the odd number of oxygens in water. If groups struggle to balance combustion equations, let them know that it helps to balance them in alphabetical order (carbon, hydrogen, oxygen). Encourage students who finish early to circulate and help give tips to others. Be positive and encouraging; balancing equations requires patience and the willingness to be wrong. Remind students that this practice is similar to how chemical engineers think, and that they are using mathematical relationships to figure out how fuels work.

Building toward 2.B.2 Develop, revise, and use models based on evidence to identify relationships between changes in matter and energy transfers that take place in a vehicle as a result of the combustion of fuel. (SEP: 2.3; DCI: PS1.B.1; CCC: 5.2)

9 · EXPLAIN ENERGY TRANSFERS AND FORCES DURING COMBUSTION REACTIONS IN VEHICLES

12 min

MATERIALS: Syringe Piston Demonstration, science notebook, *Gasoline Engine Operation*, *Balancing Fuel Equations*, chart paper, chart paper markers, M-E-F poster

Model energy transfers in the vehicle system. Say, *What other input was important for the combustion reaction to occur?* Look for students to suggest that there needs to be a spark, or energy.

Say, Let's follow up on the energy component and try to figure out how it might relate to these changes in matter we have observed. Display **slide X** and have the M-E-F poster visible.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Students may benefit from a brief word sort on cards to help clarify the relationships they are mapping back to the cylinder system. These words include: *push*, *movement*, *heat*, and *pressure*. Have students identify where each of these things occurs within the

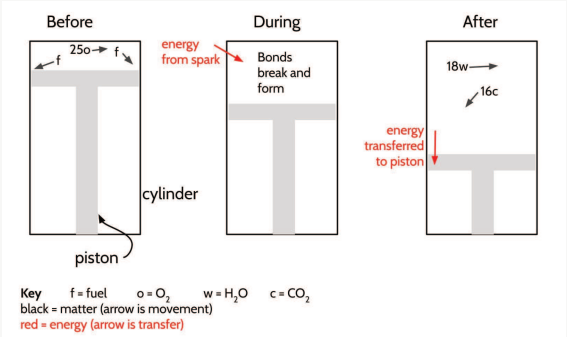
Suggested prompt	Sample student response
What evidence do we have for energy changes in the vehicle system?	We had to light it as an input. There is a higher temperature at the end than at the beginning, so energy is an output. The container feels hotter after the reaction. There is light and sound during the reaction.
Where is this energy being transferred in the vehicle system?	The energy input happens in the cylinder, with the spark. The energy moves from the pistons to the transmission and to the wheels, through the driveshaft.
So if energy transfers and matter changes go together, what part of the vehicle system should we model to explain the interaction of matter and energy?	The reaction starts in the cylinder, so I think the cylinder system.

cylinder system, then add on to that by having students identify how each of the words explains one part of the M-E-F poster. Another option is to have students use the words in a sentence and use three different-color highlighters to show M-E-F thinking.

ADDITIONAL GUIDANCE

The goal of this model is to identify where the matter and energy inputs and outputs are in the cylinder system. Students may want to represent the amounts of matter from the gasoline combustion reaction with particles, and that is okay. On day 3, students will combine the models they developed on *Balancing Fuel Equations* along with this model, to revise their initial models a second time.

Build a model showing the matter changes and energy transfers in the cylinder system. Say, *Look back at Gasoline Engine Operation and notice that the piston has four different strokes. Let's create a model of this process that summarizes what happens for a single set of four strokes, or one cycle.*✱



Display **slide Y**. Work with students to co-develop a model on a sheet of chart paper similar to that shown. Encourage students to record this model in their science notebooks.

Consider the role of forces. Direct students' attention back to the M-E-F poster and highlight the connection between energy and forces. Say, *Our new model helps us see the interactions between matter and energy, but we still need to consider forces. Remember, forces help transfer energy. We conducted three demonstrations that let us better account for the matter changes and energy transfers in the combustion reaction. I have another demonstration that may help us identify where forces are in the cylinder system to help further explain energy transfers.*

Conduct the Syringe Piston Demonstration. Display **slide Z**. Be sure to point out that the syringe is closed, so no air or water can enter or exit the syringe. After conducting the demonstration, give students a few minutes to record their answers to the questions on the slide.

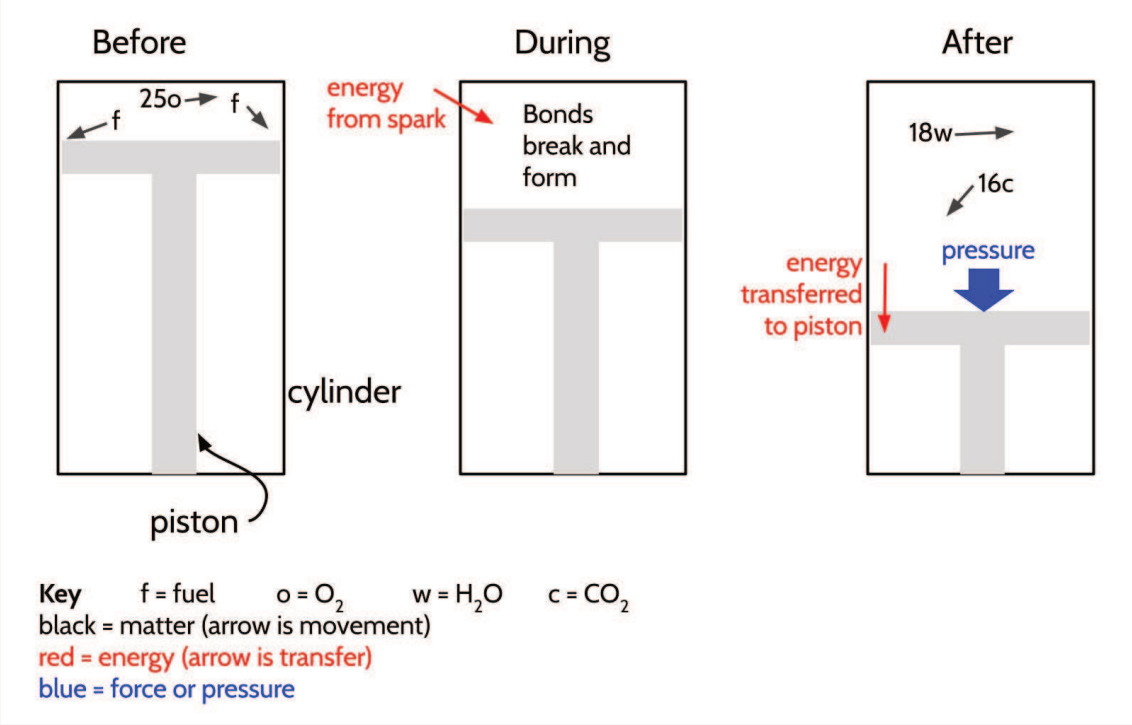
ALTERNATE ACTIVITY

If you have time, students may conduct this investigation in small groups. Provide enough materials for each pair or group of students to investigate the phenomenon.

Suggested prompt	Sample student response
What happens to the volume of the syringe?	It gets bigger. The space inside the syringe expands.
What evidence of forces do you see?	The plunger of the syringe is moving.
What is causing the forces?	Air particles heat up, move more, and push on the plunger of the syringe.
How is energy transferred by the forces?	The plunger moves because the hot air particles transfer their energy by pushing on the plunger.
How could we represent this in our model?	Arrows on the particles of carbon dioxide and water vapor.

Develop a definition of pressure. Say, *That would be a lot of little arrows! Chemists do not like to draw all these arrows — they like to think about the combined effect of all these little hits on something, spread out over an area. They call this* pressure.

Add a single, large arrow labeled *pressure* to the model as shown. At this point, title the model, "M-E-F Model of the Engine Cylinder."



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students develop and revise models to incorporate evidence from models and investigations to track and identify changes in matter and energy transfers. (SEP: 2.3; CCC: 5.2)
- Students determine that combustion reactions result in the rearrangements of reactant molecules into two possible products. (DCI: PS1.B.1)
- Students suggest that energy is released during combustion reactions to explain changes in the speed of product particles. (DCI: PS1.B.1)
- Students identify that increased forces as a result of changes in particle speed due to a chemical reaction transfer energy, causing objects to move. (DCI: PS1.B.1; CCC: 5.2)

What to do: If students do not identify the relationship between forces (pressure) and energy released from the combustion reaction, that is okay. They will have a chance to further develop those ideas on day 3. Encourage students to use the word "hits," so that they talk about individual atoms, as well as "pressure," which is a lot of atoms' hits.

Building toward 2.B.3 Develop, revise, and use models based on evidence to identify relationships between changes in matter and energy transfers that take place in a vehicle as a result of the combustion of fuel. (SEP: 2.3; DCI: PS1.B.1; CCC: 5.2)

Display **slide AA**. Have students share their past experiences with the term *pressure*. After having students consider where we observed changes in pressure within the cylinder system, co-construct a definition for pressure. Have students add the term *pressure* to their Personal Glossaries.

Suggested prompt	Sample student response
Where else have you heard the term pressure?	Peer pressure. Talking about stress. Tires. Basketballs and other inflatable stuff.
Where is the pressure coming from in those cases?	Friends. Lots of little responsibilities in life. Air in a tire or ball.
Do these examples fit the definition of a lot of little things pushing over an area?	Yes. Sort of, we often mean it to be about pushing over time and not an actual area.

End of day 2

10 · NAVIGATE

5 min

MATERIALS: science notebook, "M-E-F Model of the Engine Cylinder" poster

Make predictions about how changes in energy affect pressure. Have the "M-E-F Model of the Engine Cylinder" poster visible. Display **slide BB**. Say, *One way we are able to measure energy transfer in a system is through temperature changes. We noticed that the temperature increased after the combustion reaction occurred. With a partner, think about what impact this might have on the pressure inside an engine cylinder.* Have students turn and talk with a partner for two to three minutes about the prompts on the slide. Ask for a few volunteers to share what they discussed.

ALTERNATE ACTIVITY

Building prerequisite understandings: If students are not familiar with some of the ideas of kinetic molecular theory initially built in middle school and returned to in *Polar Ice Unit*, they can create a visualization using the following online simulation. Simply have students use the pump to add air molecules. Then have students make observations about the changes that occur when they manipulate the "heat and cool" mechanism: https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_all.html

Suggested prompt	Sample student response
What would happen to the pressure inside the cylinder if the temperature of the gasses increased?	It should increase because the gasses would move even faster and push even more on the piston.
How would this affect the movement of the vehicle?	The vehicle might move faster because the pistons would turn the spinning part more.

Say, *We have really figured out a lot! Let's use this information to revise our initial models a third time.*

11 · REVISE MODELS TO INCORPORATE NEW UNDERSTANDINGS

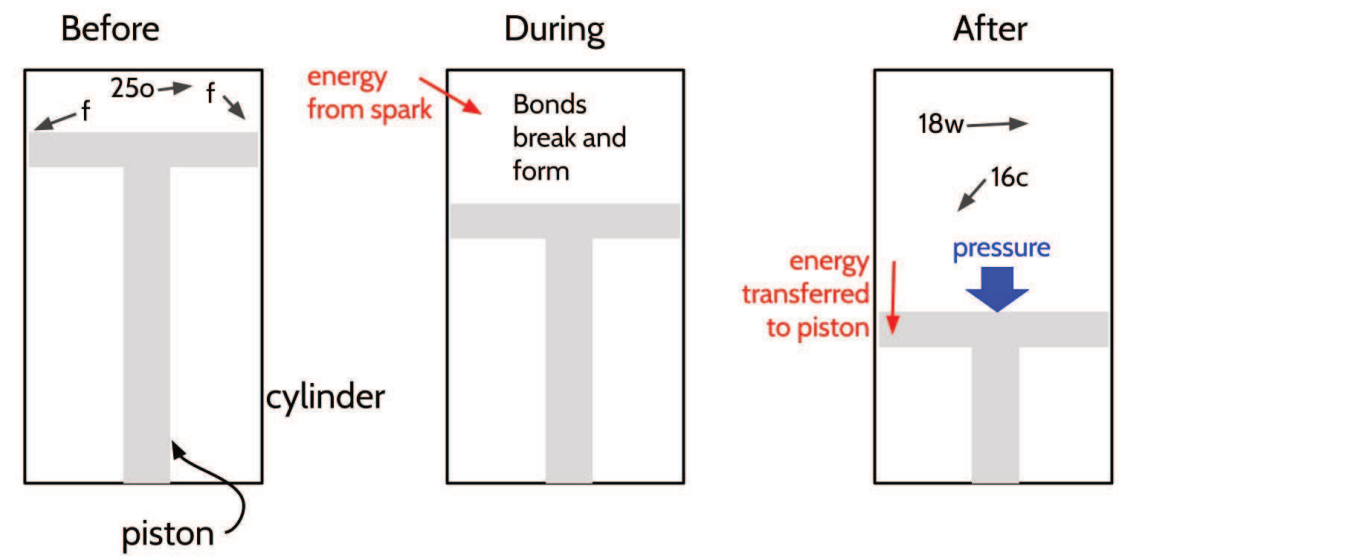
7 min

MATERIALS: *Initial Fuel Model*, *Gasoline Engine Operation*, *Balancing Fuel Equations*, *Revised Gasoline Model*, science notebook, "M-E-F Model of the Engine Cylinder" poster, initial consensus model, M-E-F poster

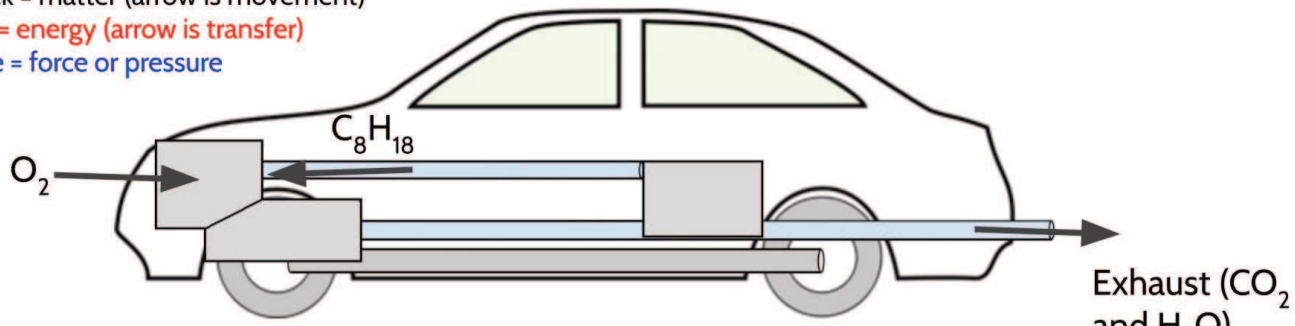
Revise models to incorporate new understandings. Display **slide CC**. Distribute *Revised Gasoline Model* and give students time to create their own revised models. They may also wish to leverage one or more of the following materials to support their thinking:

- *Initial Fuel Model*
- *Gasoline Engine Operation*
- *Balancing Fuel Equations*

A sample model is shown.



Key f = fuel o = O_2 w = H_2O c = CO_2
black = matter (arrow is movement)
red = energy (arrow is transfer)
blue = force or pressure



$$2C_8H_{18} + 25O_2 \rightarrow 18H_2O + 16CO_2$$

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students develop and revise models to incorporate evidence from models and investigations to track and identify changes in matter and energy transfers. (SEP: 2.3; CCC: 5.2)
- Students develop a model to track matter flows in combustion reactions by balancing chemical equations. (SEP: 2.3; CCC: 5.2)
- Students determine that combustion reactions result in the rearrangements of reactant molecules into two possible products. (DCI: PS1.B.1)
- Students suggest that energy is released during combustion reactions to explain changes in the speed of product particles. (DCI: PS1.B.1)
- Students identify that increased forces as a result of changes in particle speed due to a chemical reaction transfer energy, causing objects to move. (DCI: PS1.B.1; CCC: 5.2)

What to do: Students may not consider the balanced chemical equation a model, but stress the importance of that mathematical model in the explanation of, "How is gasoline used to provide energy to make a vehicle move?". Provide written feedback if possible, as students will need to have ideas in this model solidified for the rest of Lesson Set 1. If students miss one of the three dimensions, remind them of the portion of the lesson in which those ideas were built.

Building toward 2.B.4 Develop, revise, and use models based on evidence to identify relationships between changes in matter and energy transfers that take place in a vehicle as a result of the combustion of fuel. (SEP: 2.3; DCI: PS1.B.1; CCC: 5.2)

ALTERNATE ACTIVITY

Extension opportunity: If students bring expertise about other mechanical components throughout the engine or vehicle to the table, you may incorporate them into the model. If students have additional questions about mechanical components that they cannot answer for each other, you may have them research vehicles in or out of class, depending on time constraints. You could also bring in a mechanic or automotive technology student as an expert to help answer students' questions. Such a visit might be best placed at the end of Lesson Set 2, as students could ask remaining questions about road vehicles that use different fuels.

12 · ANALYZE CHARACTERISTICS OF OTHER FUELS

10 min

MATERIALS: *Fuel Data Comparisons*, internet-connected device, https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FnRytalM9fBnZ9n5aPE1m%2Ffile.json, Gasoline and Diesel Fuel Data Cards (optional)

Navigate to other fuels. Say, *We had questions about other fuels too, many of which seemed similar to gasoline. But do they work the same way?* Accept all ideas.

Point out that we are unsure and should examine more information about the fuels. Say, *Let's analyze some quantitative and qualitative data for various fuel sources.*

Display **slide DD**. Use the prompts on the slide to lead a class discussion of what we know about other fuels and their applications.

Suggested prompt	Sample student response
What were some of the differences between the types of fuels?	Types of vehicles. Sources. Energy released and CO_2 production. Whether or not they were chemically similar to gasoline (i.e., carbon-based).
What needs to happen to the fuel for the vehicle to be forced forward?	It needs to move to the engine. It needs to be ignited by a spark plug and must provide enough energy. Its molecules must be broken down during a chemical reaction.
What characteristics might make a fuel ideal to use in a vehicle?	The fuel has energy that can be transferred into the cylinder system. The fuel can be ignited. The fuel produces less CO_2.

Summarize student responses. Say, *Okay, we know what a fuel needs to be able to do. Let's see if we can use a data set to learn more about the other carbon-based fuels we investigated in Lesson 1.*

ADDITIONAL GUIDANCE

Some of the data represented in the CODAP data set are calculations using values published from government and journal articles. Please refer to *CODAP Calculations* for the calculations used in the CODAP dataset.

Decide on an investigation question as a class. Display **slide EE** and distribute *Fuel Data Comparisons*. Say, *I have compiled a data set comparing currently used fuels across multiple measures. What kinds of investigative questions might help us identify, or design around, a different fuel?* Discuss as a class what question(s) can be answered using the data on the slide and in the handout. Possible investigation questions include:

- Which fuels tend to be easier to ignite?
- Which fuels help us go farther?
- Which fuels have more energy, but have less CO_2 emissions?

ADDITIONAL GUIDANCE

Gasoline Gallon Equivalent (GGE) is a comparison tool used to compare the relative energy found in each of the fuels. The number shown in the table represents the gallons of gasoline that would match one gallon of the alternative fuel. Above 1.0 means the alternative fuel contains more energy. Below 1.0 means the alternative fuel has less. For more information, see https://afdc.energy.gov/fuels/properties.

Once the class has decided on an investigation question, ask students to record it in *Fuel Data Comparisons* under Question 1.



Small groups work on Fuel Data Comparison. Organize students into small groups of two to four. Make sure each group has access to an internet-connected device that can run CODAP. Display **slide FF** and point students to https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FnRytaIM9fBnZ9n5aPE1m%2Ffile.json. Give small groups about 7 minutes to create graphs that show patterns in potential fuel viability, and to record their ideas for questions 2-5 in *Fuel Data Comparisons*. Tell students to be prepared to share the graph(s) that helped them answer the investigation question.

ADDITIONAL GUIDANCE

If students have not worked with CODAP before, show them how you can drag different measures to the *y-axis* of the graph to allow them to be compared visually across fuels.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students analyze a CODAP data set to identify patterns of energy, efficiency, and carbon emission for various fuels. (SEP: 4.6; CCC: 1.3)
- Students determine that diesel and biodiesel provide more energy than gasoline. (DCI: PS1.B.1)
- Students suggest that due to diesel's energy content and abundant usage, it could serve as an optimal alternative to gasoline. (SEP: 4.6; DCI: PS1.B.1)

What to do: Students may need guidance on setting up effective graphs. Walk through one measure as a class, emphasizing a focus on which fuels are "good" on that criterion. Ask students to refer back to their models in *Gasoline Engine Operation*, looking particularly at the inputs needed to transfer energy into the cylinder system or the outputs that could be environmentally problematic. Be sure to stress that students identify which values should be higher and which should be lower to optimize combustion.

Building toward 2.C Analyze data using CODAP to identify patterns in carbon-based fuel characteristics that optimize the successful movement of a vehicle when burned in an internal combustion engine. (SEP 4.6; DCI: PS1.B.1; CCC 1.3)

13 · BUILDING UNDERSTANDINGS DISCUSSION ABOUT FUEL COMPARISON

8 min

MATERIALS: *Fuel Data Comparisons*

Facilitate a Building Understanding Discussion.✱ Display **slide GG**. Use the following prompts to guide the class in sharing their responses to the questions on *Fuel Data Comparisons*.

Suggested prompt	Sample student response
What do we need in a fuel to optimize the movement of our vehicles?	We need the fuel to provide a lot of energy. We need the fuel to be able to ignite to start the energy transfer. We need to minimize CO_2 emissions.
What patterns did you notice?	Diesel and biodiesel seemed to share similar characteristics. Methanol would not be a good candidate because they need the engine to get really hot for them to combust. Gasoline, ethanol, and liquid propane seemed to share similar characteristics.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful kind of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. As students share, encourage them to use evidence from the graphs they generated in CODAP to support their ideas. Your role during the discussion is to invite students to share conclusions and claims and push them to support their conclusions and claims with evidence. Students can disagree with each other, and the class does not need to reach consensus on all ideas shared. Areas of disagreement can motivate future investigations.

Suggested prompt	Sample student response
What do the patterns make you wonder about?	Can you use diesel in a vehicle engine? Why does diesel combust at a higher temperature than gasoline? What causes some fuels to combust at higher temperatures?

Say, *So what I hear you saying is that we need to know more about diesel and biodiesel. It seems like those fuels are similar to each other, but not to gasoline. I also heard you say that diesel/biodiesel contain more energy and produce less CO_2, but are not being used as widely as gasoline. This is curious. Let's take a look at what diesel looks like as it combusts within an engine.*

ADDITIONAL GUIDANCE

Students will likely identify that diesel and biodiesel are relatively similar, whereas in some graphs gasoline tends to be grouped near ethanol and/or liquid propane. The lack of widespread use of diesel and biodiesel in personal vehicles can be used as a launching point to further discuss their combustion in the forthcoming investigation, especially as students notice that diesel and biodiesel have more energy, make vehicles go farther, and release less CO_2.

14 · ANALYZE CHARACTERISTICS OF OTHER ENGINES

10 min

MATERIALS: Fire Syringe Demonstration, *Diesel Engine Operation*, science notebook, *Gasoline Engine Operation*, Gasoline and Diesel Fuel Data Cards (optional)

Compare gasoline and diesel engines. Display **slide HH** and distribute *Diesel Engine Operation*. Give students a few minutes to record similarities and differences in the engine types in their science notebooks. Students may also want to review *Gasoline Engine Operation*.

Suggested prompt	Sample student response
What is similar between the two types of engines?	There were four strokes. Fuel and air came in and exhaust went out. There was fuel igniting and pushing on the piston, causing other parts to turn.
What is different between the two types of engines?	There wasn't a spark plug in the diesel engine. The fuel was injected after the air was compressed. ✱ The fuel ignited just because it was in hot, compressed air.

Problematize the lack of a spark plug. Say, *It seems strange that fuel and air could just catch on fire. Let's test whether that is the case.*

Display **slide II**. Complete the Fire Syringe Demonstration using the following steps.

- Place a small piece of cotton in the fire cylinder.
- Push down on the plunger quickly.

Ask students to share what they observed; accept all responses. Say, *This happens so quickly! Let's watch a slow-motion video to see if we can make some additional observations.* Show https://youtu.be/kiYfaaibWL0. Discuss what students saw using the prompts below.

✱ ATTENDING TO EQUITY

Support all students in accessing the ideas by using their own language for "compression" at this point. Language like "squished" is perfectly acceptable for reasoning about the diesel engine. This strategy supports emerging multilinguals in achieving the lesson-level performance expectation as well.

Suggested prompt	Sample student response
What had to happen for the substance to catch fire?	The piston had to be pushed down quickly. There had to be something to catch fire.
What catches fire instead of cotton in a diesel engine?	The fuel catches fire.
What is happening at the particle level when the cylinder is compressed?	The particles must be pushed together. They hit each other more often and speed up.

15 · NAVIGATE

5 min

MATERIALS: *Progress Tracker*

Start the Progress Tracker. Distribute *Progress Tracker*. Display **slide JJ** and give students a few minutes to add the first row to their trackers. A sample entry is shown. Students may also add new criteria and constraint ideas to the box at the top, if any came up in the lesson.

ADDITIONAL GUIDANCE

Throughout the unit, examples are provided in the third column for *Avoid, Shift*, and *Improve.* Students are only asked to address one of these. Leave this a free choice for students; one student may read about electric vehicles in Lesson 9 and choose to focus on *shifting* our transportation to electric vehicles, while another be more skeptical and focus on the need to *improve* EV technology before making such a move.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	Engineering implications Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
Carbon-based fuels are burned to release energy. All carbon-based fuels react in a specific way, where oxygen is combined with the fuel and energy is added to release energy and produce carbon dioxide and water vapor. This is called a combustion reaction. When this takes place in the cylinder system of an engine, the hot gasses in the cylinder push on the piston, causing it to move. The piston is connected to the wheels through several different components in the vehicle. We saw this with investigations and models where we traced energy and matter.	Carbon-based fuels release carbon dioxide when burned. That is one of the reaction products, so another fuel would be needed if the goal was to emit no carbon dioxide. Gasoline and diesel have relatively high energy released. Different fuels burn at different temperatures, so you need one that burns at the right temperature for the engine.	Avoid: Avoid fuels with low energy released values as they don't provide enough energy to move vehicles greater distances. Shift: Look at using diesel or biodiesel because they have higher energy released values but produce less CO_2 than gasoline. Improve: Find a way to minimize matter outputs while maximizing energy outputs.

Navigate to the next lesson. Display **slide KK**. Elicit big ideas from the Progress Tracker, which will likely include the need to add energy through a spark. Say, *In order for fuels to combust, there must be an initial input of energy. But within the diesel engine cylinder no spark is provided, unlike in the gasoline engine. What is going on here? Where is the energy coming from to combust diesel in its engine system?* Accept all responses.

Additional Lesson 2 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. Students move between visual models and text descriptions of matter changes, energy transfers, and forces in a vehicle. They revise a visual model to explain how gasoline provides energy to make a vehicle move. They then compare models of gasoline and diesel engines.
SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	CCSS.MATH.CONTENT.HS.N-Q.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and interpret the scale and the origin in graphs and data displays.~~ Students work as a class and in small groups to balance chemical equations for three different combustion reactions. This work requires that students use coefficients as units to help guide them when balancing the chemical equations.

LESSON 3: How can diesel engines be working so differently from gasoline engines?

PREVIOUS LESSON

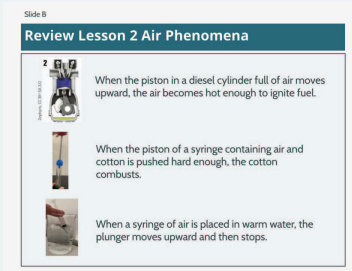
We examined diagrams that show how gasoline provides energy to a vehicle. We analyzed the changes that occur using our M-E-F poster and tested our ideas by burning ethanol. We modeled changes in matter, energy, and forces. We analyzed data to identify more optimal fuels. We developed a model to summarize our ideas, then examined how diesel engines work and compared them to gasoline engines.

THIS LESSON

INVESTIGATION

1 day





We revisit three air-related phenomena from Lesson 2 and think about how the properties of air change during the phenomena. We analyze air property data using CODAP to identify qualitative relationships between properties. We attempt to use the Combined Gas Law to quantify how pressure changes in the fire syringe and recognize the need for absolute temperature. We use this approach to determine the pressure needed to combust different fuels in a diesel cylinder. Finally, we use M-E-F thinking to clarify the mechanism of energy transfer from the moving piston to the air particles as the cause of the temperature increase.

NEXT LESSON

We will investigate why an energy input was needed to start the combustion reactions. We will figure out that matter is conserved. We will use magnet marbles and a computer model to identify and quantify the energy and forces in the reaction. We will build understanding about what is happening to the reactants during combustion reactions.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1



WHAT STUDENTS WILL DO

3.A Evaluate the impact of the relationship between pressure, volume, and temperature of air (data) on the working model of a diesel engine by identifying energy transfer from the motion of the piston to the air particles in the cylinder as the cause of the temperature increase (effect). (SEP: 4.5; DCI: PS3.A.2, PS3.B.2; CCC: 2.2)

WHAT STUDENTS WILL FIGURE OUT

- In a diesel engine, compressing air increases the air temperature above the ignition temperature of the fuel, causing the fuel to combust when it is injected.
- We can determine how much pressure must be applied to the piston for the gas inside the diesel cylinder to reach the ignition temperature of a fuel using the Combined Gas Law.
- As the air in the cylinder is compressed, its temperature increases because energy is transferred from the moving piston to the air molecules.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Recall where the class left off and focus on the compression stroke in a diesel engine.	A	
2	8 min		**REVIEW AIR-RELATED PHENOMENA** Review air-related phenomena from Lesson 2 with students and establish how the properties of air change during those phenomena as a class.	B-F	Air Phenomena and Properties poster, chart paper markers
3	8 min		**ANALYZE AND INTERPRET AIR PROPERTY DATA** Have students analyze air property data using CODAP to identify qualitative relationships between properties.	G-H	*Air Property Data*, internet-connected device
4	7 min		**INTERPRET RELATIONSHIPS BETWEEN AIR PROPERTIES** Make sense of relationships between gas properties and analyze the Combined Gas Law as a class.	I-K	*Air Property Data*, Air Phenomena and Properties poster, Air Property Trends poster, chart paper markers
5	8 min		**ANALYZE THE FIRE SYRINGE WITH THE COMBINED GAS LAW** Lead the class to attempt to calculate the pressure needed to combust cotton in the fire syringe. Then guide students to think about relative temperature scales and kinetic energy, and to use an absolute temperature scale to recalculate pressure.	L-P	https://www.openscied.org/curriculum/high-school/combined-gas-law/, internet-connected device, fire syringe (optional)
6	7 min		**DETERMINE PRESSURE NEEDED TO IGNITE DIESEL FUEL** Have partners determine the pressure needed to ignite a fuel of their choice in a diesel engine, then discuss energy inputs as a class.	Q-S	*Diesel Combustion Pressure*, internet-connected device, M-E-F poster
7	4 min		**NAVIGATE** Have students individually add questions to sticky notes and update the DQB as a class.	T	3x3 sticky notes, colored markers, Driving Question Board

End of day 1

Lesson 3 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Air Property Data* • https://www.openscied.org/curriculum/high-school/combined-gas-law/ • *Diesel Combustion Pressure* • 3x3 sticky notes • colored markers	• internet-connected device	• Air Phenomena and Properties poster • chart paper markers • Air Property Trends poster • fire syringe (optional) • M-E-F poster • Driving Question Board

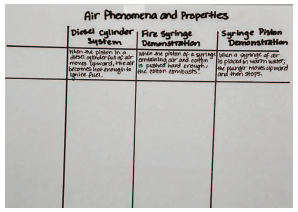
Materials preparation (20 minutes)

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

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

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

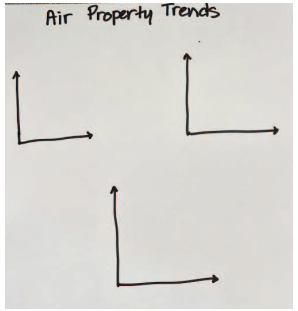
Have the M-E-F poster ready for display.



Using a piece of chart paper in landscape orientation, prepare the Air Phenomena and Properties poster with four columns as shown. Add the following phenomena and descriptions in columns 2-4, respectively:

- Diesel Cylinder System - When the piston in a diesel cylinder full of air moves upward, the air becomes hot enough to ignite fuel
- Fire Syringe Demonstration - When the piston of a syringe containing air and cotton is pushed hard enough, the cotton combusts.
- Syringe Piston Demonstration - When a syringe of air is placed in warm water, the plunger moves upward and then stops.

Using a piece of chart paper in portrait orientation, prepare the Air Property Trends poster as shown.



Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS3.A.2 Definitions of Energy:** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, ~~sound, light,~~ and thermal energy.
- **PS3.B.2 Conservation of Energy and Energy Transfer:** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.

Crossout explanation: In this lesson students identify energy transfer from the moving piston (motion) as the cause of an increase in the temperature of air (thermal energy) during the compression stroke of a diesel engine. Sound and light do not play a significant role in the compression of air.

This lesson slowly builds to the Combined Gas Law by revisiting three air-related phenomena from Lesson 2. Once pressure, volume, and temperature are identified as important properties of a gas, students analyze and qualitatively interpret empirical *relationships* between two properties while a third is held fixed (SEP: 4.5). The need to understand how air behaves when all three properties change motivates the need for the Combined Gas Law. Students previously used this element to evaluate the impacts of data on their model of sea-level rise in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

As students attempt to use the Combined Gas Law to determine the pressure needed to ignite cotton in the fire syringe, temperature is problematized when students obtain different results using different temperature scales and are prompted to consider the implications of negative temperature for particle kinetic *energy*. This motivates the need for the Kelvin scale which is directly proportional to the average particle kinetic energy, with 0 K corresponding to zero kinetic energy (DCI: PS3.A.2).

This lesson builds on ideas about the conservation of energy and energy *transfer* developed in *Polar Ice Unit* and *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. This lesson leverages ideas about the kinetic energy of particles developed in *Polar Ice Unit*, as well as one middle school idea about kinetic energy from *OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)*. Specifically, students use their understanding of the kinetic energy of an object being related to its mass and speed to identify the energy transfer from the moving piston to the air particles as the cause of the temperature increase. This requires thinking about how *energy transfer and its effects can be framed at various scales given that energy is conserved* (DCI: PS3.B.2; CCC: 2.2). In this lesson, these relationships are treated qualitatively--i.e., a larger, faster object has more kinetic energy than a relatively small or slower one.

Where We Are NOT Going

The focus of this lesson is not on naming and learning the empirical gas laws as they are not explicitly included as DCIs in the NGSS. Instead, students analyze data to identify qualitative relationships between pressure, volume, and temperature. Students are then provided with and use the Combined Gas Law because it helps them understand the quantitative empirical relationship between pressure, volume, and temperature for a fixed amount of gas in a closed system (i.e., the fire syringe or the diesel cylinder system). This helps students understand how pressure and volume in a diesel cylinder must change to achieve a fuel's ignition temperature and provides a starting point for reasoning through the associated energy transfers. Students are not required to do Combined Gas Law calculations themselves, given that the focus of this lesson is on the impact of data on students' mental models of diesel engines rather than on computational thinking. Derivation of the Ideal Gas Law is not necessary, non-trivial, and beyond the scope of the lesson, although suggestions are provided for its use in an extension.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

3 min

MATERIALS: None

Remind ourselves of where we ended last class. Display **slide A** and use the prompts on the slide to navigate into today's work. As students share their ideas, use the diesel cycle diagram on the slide to frame what the class has figured out (how the combustion of fuel during the power stroke moves a vehicle), and the work ahead (why the temperature of air increases during the compression stroke).

Suggested prompt	Sample student response
What did we figure out last class about how engines make vehicles move?	A chemical reaction called combustion happens between air and fuel in the cylinders of an engine. Energy released during combustion moves the piston, which ultimately makes the wheels move. Some energy is needed to make the combustion reaction happen. For gasoline engines it's a spark, but for diesel engines it's compression.
What is still unclear about diesel engines in particular?	We don't really know why the compression causes combustion.

ADDITIONAL GUIDANCE

This lesson ties to the following questions on the Driving Question Board:

- Why doesn't diesel need a spark?
- Why do cars take gasoline while trucks take diesel?
- Does diesel burn hotter?
- Is diesel more efficient?
- Does diesel work the same as gasoline?
- Can we put any fuel in our cars?
- Can we put diesel in our cars?

2 · REVIEW AIR-RELATED PHENOMENA

8 min

MATERIALS: science notebook, Air Phenomena and Properties poster, chart paper markers

Review related phenomena from Lesson 2.✱ Say something like, *We have already worked with a few phenomena involving air, in addition to the diesel cylinder system. Does anyone remember what those were?* Show **slide B** and use the images and text on the slide to review three phenomena from Lesson 2. Then display **slide C** and ask students to turn and talk with a partner about what is similar and different about the phenomena. If needed, you can return to **slide B** as students discuss similarities and differences.

Discuss similarities and differences as a class. After student pairs have had time to discuss the prompts, display **slide D** and bring the class together for a quick sharing of ideas.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: The arrows and symbols in this section support students in understanding relationships and the crosscutting concept of Cause and Effect with tools that are not linguistic. This can be helpful for all students as they work with gas laws.

Suggested prompt	Sample student response
What is similar about these phenomena?	In all cases, there is a part that moves. All of them have a space full of air that is closed off from the surroundings. In all of them the air inside the closed space gets hotter. Temperature, volume, and pressure probably change in each one.
What is different about them?	The parts are made of different materials. Different causes of the movement of the moving parts–warm water bath, hand pressing on a part. For the fire syringe, cotton is in the closed space with the air. Air is compressed for the diesel cylinder and fire syringe, but it expands for the syringe in warm water.

Suggest creating an Air Phenomena and Properties poster. Thank students for their contributions. Say, *I hear you saying that all of these phenomena involve something happening with air, a gas, in a closed system. You started talking about some important properties of air/gases that probably play a role. Let's record what we know or do not know about how those properties change when the phenomenon happens.* Have the Air Phenomena and Properties poster you prepared ahead of time in a location where all students can see it.

ADDITIONAL GUIDANCE

The phenomena used in this lesson to motivate the need for the Combined Gas Law all involve air, a gas. It is okay to use either term as long as the class is not confusing gas, the state of matter, with gasoline, the fuel. If the class begins referring to air as a gas, periodically remind students that we are talking about the air in an enclosed space.

Define relevant quantifiable properties of air. Suggest that we can get on the same page by clarifying which properties we are comparing across these phenomena. Show **slide E** and use the first prompt to have students work with you to add the following to the first column of the poster:

- V = volume of the air
- T = temperature of the air
- P = pressure of the air

As you add these properties to the poster, ask students what units the class has used for these properties before and add those to the poster as well. Students will likely suggest liters (L) or milliliters (mL) for volume, and degrees Celsius (°C) or Fahrenheit (°F) for temperature.

Since *pressure* was just defined in the previous lesson, ask students to share the definitions of pressure they added to their Personal Glossaries in Lesson 2. Once the class confirms pressure as force per area, ask them what types of units they have used in the past for those two quantities. Use students' responses to define N/m^2 as the units we will use for pressure, and add it to the poster.

ALTERNATE ACTIVITY

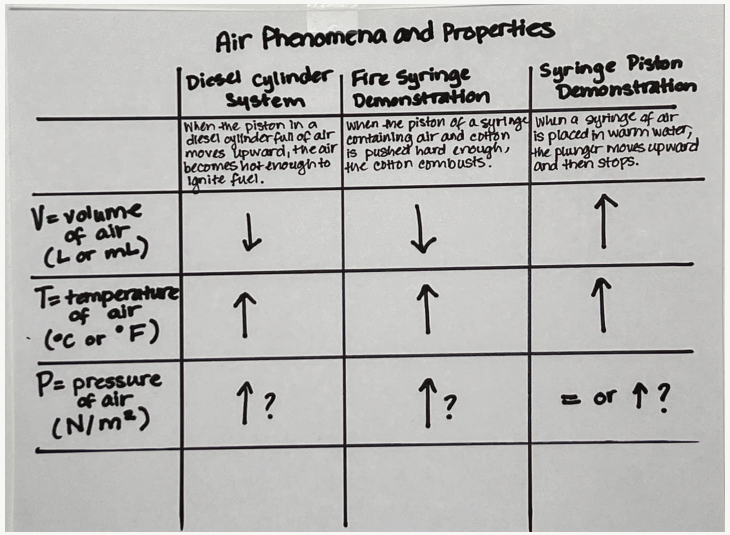
Extension opportunity: If you are required to teach the Ideal Gas Law (PV = nRT), you can add the number of moles of gas (n) to the Air Phenomena and Properties chart. Since the three phenomena from Lesson 2 all involve closed systems, students should readily conclude that n does not change.

Build the Air Phenomena and Properties poster. Use the remaining prompts on **slide E** to chart what students know about how the properties of air change in the diesel cylinder system, the Fire Syringe Demonstration, and the Syringe Piston Demonstration. Ask students to refer to the description of each phenomenon on the poster as needed. If necessary, revisit the phenomena descriptions to remind

students that they do not include any chemical reactions, like combustion. As students share, represent their thinking on the chart using the following symbols:

- ↑ for an increase
- ↓ for a decrease
- = for no change
- ? for uncertainty

An example of what a complete poster may look like is shown.



Identify patterns in air properties. Display **slide F** and ask students to look for patterns in how the properties of air change across the phenomena. Facilitate a brief sharing of ideas to articulate that although temperature increases in each, volume increases for the Syringe Piston Demonstration and decreases for the diesel cylinder system and Fire Syringe Demonstration, and we are not really sure what is going on with pressure. If it has not already come up, gain agreement that the phenomena in the diesel cylinder and fire syringe are the same, so the class can consider the fire syringe to be a less complicated version of the diesel cylinder.

3 · ANALYZE AND INTERPRET AIR PROPERTY DATA

8 min

MATERIALS: *Air Property Data*, internet-connected device

Consider analyzing air property data. Display **slide G** and say something like, *There is some relationship between the volume, temperature, and pressure of air in a closed system, but it is not entirely clear what that relationship is. Maybe looking at more data can help. If we had access to these data for a fixed amount of air, what trends would you expect to see for*

- *pressure, as volume increases?*
- *volume, as temperature increases?*
- *pressure, as temperature increases?*

If we knew how volume, temperature, and pressure were related, how could it help us understand how a diesel engine works? Give students a few minutes to discuss this with a small group. Circulate around the room to assess students' initial ideas.

Analyze and interpret air property data. Tell students that you have some data for them to analyze in CODAP to help the class identify relationships between the volume, temperature, and pressure of a fixed amount of air, a gas. Share **slide H** and ask students to pair up and access the CODAP data at https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2F7C6PjkptyiLu55GD9WfM%2Ffile.json while you distribute copies of *Air Property Data* to each student. Give students five minutes to explore the data, record trends, and explain how compressing air in the fire syringe makes it hot enough to combust cotton.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students evaluate pressure, volume, and temperature data to identify qualitative relationships between these properties. (SEP: 4.5; CCC: 2.2)

What to do: If students struggle to identify qualitative relationships between variables, suggest that they graph the independent variable on the *x*-axis and the dependent variable on the *y*-axis. If needed, point to their graphs and ask how the dependent variable on the *y*-axis changes as the independent variable on the *x*-axis increases. Students are not expected to recognize that the curve obtained for the P vs. V graph shows an inverse relationship between the two properties. Let them know it is okay to describe the relationship as a curve (as opposed to the straight lines obtained for the graphs of V vs. T and P vs. T).

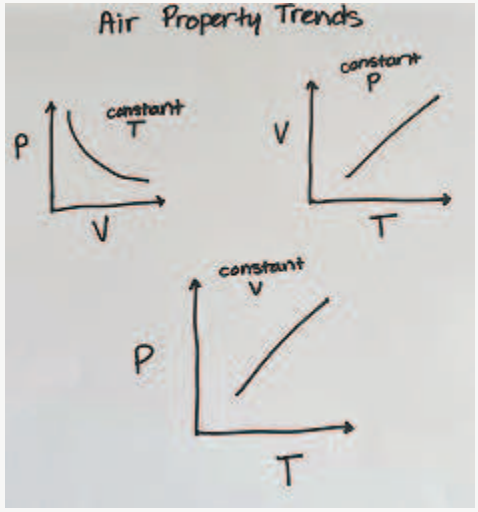
Building toward 3.A.1 Evaluate the impact of the relationship between pressure, volume, and temperature of air (data) on the working model of a diesel engine by identifying energy transfer from the motion of the piston to the air particles in the cylinder as the cause of the temperature increase (effect). (SEP: 4.5; DCI: PS3.A.2, PS3.B.2; CCC: 2.2)

4 · INTERPRET RELATIONSHIPS BETWEEN AIR PROPERTIES

7 min

MATERIALS: *Air Property Data*, Air Phenomena and Properties poster, Air Property Trends poster, chart paper markers

Document air property trends. With the Air Property Trends poster visible, show **slide I** and use the bulleted prompts to have students share the trends they observed in CODAP. Have a few partners share their observations for each trend. Once the class reaches consensus on a trend, invite a student to add a rough sketch of the trend to the Air Property Trends poster. A sample poster is shown.



ADDITIONAL GUIDANCE

The purpose is to attempt to articulate a general relationship and not to derive the Ideal Gas Law. This derivation is non-trivial and is beyond the scope of the practice of using mathematics and computational thinking. For more information, see https://pubs.acs.org/doi/10.1021/ed057p201.

Attempt to explain the Fire Syringe Demonstration. Shift the focus to the prompt on the bottom of **slide I**: *How do these trends help us explain the fire syringe?* Remind students that the fire syringe is a simplified version of the diesel cylinder system. Use the following prompts to facilitate a brief discussion to surface the need for a way to understand what happens when all three properties change. Refer to the Air Phenomena and Properties poster as needed.

Suggested prompts	Sample student responses	Follow-up questions
How do these trends help us explain the fire syringe?	With the fire syringe, volume decreases as pressure increases just like the trend in the P vs. V graph.	*Was temperature held constant for the fire syringe?*
	In the V vs. T graph, temperature decreases as volume decreases but that is the opposite of what happens in the fire syringe.	*What was held constant for the V vs. T data? Was that held constant for the fire syringe?*
Can we use these property trends (point to the Air Property Trends poster) to explain the Syringe Piston Demonstration?	Well, for that phenomenon, volume increases because temperature increases. That is what the V vs. T graph shows.	*What does that tell us about how the overall pressure changes?*
What type of relationship between air properties do we need to understand to make sense of the fire syringe?	One that tells us what happens when all three properties–volume, temperature, and pressure–change at the same time.	*We have used linear graphs before, like we see for V vs. T and P vs. T, to figure out equations. But this curved one (point to P vs. V) is more complicated...*

Introduce the Combined Gas Law. Display **slide J**. Explain to students that from the 1600s through the 1800s, as the field of chemistry developed, scientists conducted detailed investigations into the behavior of gases. Say something like, *Scientists were able to integrate all of their experimental findings into this equation called the Combined Gas Law. It works best in situations where the forces between gas particles are pretty weak, so when we use it we are setting aside our thinking about reactions for a little bit.*

ALTERNATE ACTIVITY

Extension opportunity: If you are required to teach the Ideal Gas law, you can introduce it here by replacing the Combined Gas Law on **slide J** with the Ideal Gas Law (PV = nRT). To be consistent with the units for pressure (N/m^2) introduced earlier in the lesson, initially provide the units for the gas constant, R, in N·m/mol·K before defining it using other units (e.g., J/mol·K). For reference, R = 8.31 N·m/mol·K or 8.31 J/mol·K. (SEP: 5, CCC: 5)

Consider how to use the Combined Gas Law. Display **slide K** and give students a minute and a half to discuss the prompts on the slide with a partner:

- How can we use the Combined Gas Law to understand pressure changes in the fire syringe?
- What do we need to know?

Invite a few partners to share their ideas and then suggest trying it out together.

5 · ANALYZE THE FIRE SYRINGE WITH THE COMBINED GAS LAW

8 min

MATERIALS: https://www.openscied.org/curriculum/high-school/combined-gas-law/, internet-connected device, fire syringe (optional)

Share quantitative property data for the fire syringe. Display **slide L** and walk students through the data provided on the slide. Point out that

cotton spontaneously ignites (without a spark) in air at 400 °C (752 °F). Explain that the values for T_1 and P_1 are typical values for air at room temperature and atmospheric pressure, and the volumes are estimates for the fire syringe.

Try to calculate the pressure needed to ignite cotton. While still showing **slide L**, ask students to use the link on the slide to access an individual copy of https://www.openscied.org/curriculum/high-school/combined-gas-law/ and input the known quantities to calculate P_2. When students ask which temperature units to use, suggest that they try using both to see what happens.

Interpret calculations. After a minute, ask students to share their results for P_2. If they share numerical values without units, push them to provide units for pressure (N/m^2). The results students obtain will depend on the units they used for temperature:

- Students who used temperatures in °C will obtain 20,265,000 N/m^2.
- Students who used temperatures in °F will obtain 11,205,353 N/m^2.

Elevate this discrepancy by asking, *Which one is the correct value?*

Problematize temperature. Show **slide M** and say, *Let's step back for a moment and think about the Fahrenheit and Celsius temperature scales. What do we know about them?* Use the prompts on the slide to elicit students' ideas.

Suggested prompt	Sample student response
What phenomena are used as their low and high temperature reference points?	Don't they use the freezing or boiling points of water? I've heard that Fahrenheit body temperature is something like 98°.
What types of situations are these scales useful in?	Our everyday lives, like knowing the outdoor temperature to see if it will rain or snow. We also freeze food to preserve it or boil water to kill bacteria. There is a range of temperatures between the freezing and boiling of water where people are comfortable and don't get injured.
What do relative scales like these tell us about the average kinetic energy of gas particles?	Well, higher temperatures on either scale mean higher average kinetic energy... Since they are relative scales, they can only tell us about relative kinetic energies.

Consider how kinetic energy decreases with temperature. Say something like, *OK, so the Fahrenheit and Celsius scales are useful for our everyday experiences and to determine relative kinetic energies of particles. What does a lower or even negative temperature mean in terms of kinetic energy? What would a gas look like once all the kinetic energy is gone?* Display **slide N** and discuss the prompts to get a few ideas on the table.

Suggested prompt	Sample student response
What does a lower or even a negative temperature mean in terms of kinetic energy?	We know particle kinetic energy decreases as temperature decreases, so a lower temperature means lower kinetic energy. Maybe a negative temperature means negative kinetic energy?

Suggested prompt	Sample student response
What would a gas look like once all the kinetic energy is gone?	The particles stop moving altogether? As kinetic energy decreases, a gas would turn into a liquid, and then a solid. Maybe particles in a solid take up even less space when they're not moving.

Introduce an absolute temperature scale. Share **slide O** and explain to students that scientists in the mid 1800s wondered about the same things and found that if they extrapolated a graph of volume vs. temperature to the point where the volume falls to zero, the temperature obtained was always around -273.15 °C. This theoretical temperature, where the gas particles cease to move and have no kinetic energy, is called *absolute zero*. Tell students that for gas law calculations, temperatures on the Kelvin scale must be used. Point out that temperatures in degrees Celsius can be converted to Kelvin by adding 273.15.

Recalculate the pressure needed to combust cotton. Display **slide P** and ask students to use the link to the spreadsheet to recalculate the pressure needed to combust cotton in the fire syringe, this time with temperatures in Kelvin (as shown on the slide). Students should obtain a pressure of 2,326,690 N/m^2.

6 · DETERMINE PRESSURE NEEDED TO IGNITE DIESEL FUEL

7 min

MATERIALS: science notebook, *Diesel Combustion Pressure*, internet-connected device, M-E-F poster

Predict the pressure needed to combust diesel fuel. Share **slide Q** and point out that the pressure needed to combust cotton is about 23 times greater than atmospheric pressure. Read the prompts and ask students to take a moment to jot in their science notebooks how much pressure they think is needed to combust fuel in a diesel cylinder.

Determine the pressure needed to ignite fuel in a diesel cylinder. Display **slide R**, distribute *Diesel Combustion Pressure*, and ask students to work with a partner to determine how much pressure the piston in a diesel cylinder system needs to apply to combust a fuel of their choice. Give partners 3-5 minutes to complete their calculations using *Diesel Combustion Pressure*. As students work, circulate around the room to check their answers:

- For diesel as a fuel, P_2 = 2,850,198 N/m^2 (28x atmospheric pressure)✱
- For biodiesel as a fuel, P_2 = 3,977,719 N/m^2 (39x atmospheric pressure)
- For DME as a fuel, P_2 = 4,207,274 N/m^2 (41x atmospheric pressure)

ALTERNATE ACTIVITY

Extension opportunity: If you introduced the Ideal Gas Law earlier and want to provide students with additional opportunities, you can ask them to determine the amount of fuel that needs to be injected to stoichiometrically react with oxygen in the diesel cylinder system. Students can use the initial conditions in *Diesel Combustion Pressure* to determine the moles of air if you provide volume in m^3. They can then use the fact that air is 21% oxygen to determine the moles of oxygen. Using the balanced equation for combustion for a given fuel, students can determine the moles of fuel needed. This can be further extended to a determination of the mass and volume of fuel injected using values for the fuel's molecular weight and density.

Connect back to the lesson question. Say, *Our work today started with us wanting to know how a diesel engine can work so differently from a gasoline engine. To do that, we need to understand how compressing air in a diesel cylinder makes the air hot enough to ignite diesel fuel when it is injected. Fortunately, scientists and engineers have designed engines to do this, using their understanding of the relationships between volume, temperature, and pressure. Today we used the Combined Gas Law to determine how much pressure the piston in a diesel cylinder system has to apply to heat the air to the fuel's ignition temperature. But where does that energy come from, and what does it do?*

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

The comparison to atmospheric pressure here not only provides an opportunity for students to engage in scale thinking, but also supports meaning-making around the data as students apply it to their working model of how diesel-like engines work.

Leverage M-E-F thinking. Display **slide S** and use the prompts and image on the slide, as well as the M-E-F poster, to gain consensus on the source of the energy that is transferred to the air as it is compressed.

Suggested prompts	Sample student responses	Follow-up questions
Compressing air increases its temperature. How do we know there is energy in the diesel cylinder system?	The air heats up, so the average kinetic energy of the particles increases. The piston is moving, so it also has kinetic energy.	*Are the air particles the only thing moving?*
OK, so forces transfer energy (point to the M-E-F poster). What forces are acting on the air particles?	They collide with each other. They collide with the sides of the cylinder and the piston too.	*What energy transfers happen during those collisions?*
Where and how is energy being transferred to the air particles?	In collisions, energy is transferred from the thing with higher kinetic energy to the thing with lower kinetic energy. From the piston, because it's also moving. The piston is big and heavy compared to an air particle, so it must have a lot of kinetic energy.	*What part of the diesel cylinder system has high kinetic energy during compression?* *Is it possible that energy is being created out of nowhere?*
What happens after energy is transferred into the system?	Combustion. There's a reaction. The fuel is ignited and starts burning.	*Do we know why that happens?*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students identify energy transfer from the motion of the piston to the air particles in the cylinder as the mechanistic cause of the temperature increase (effect) at the particle level. (DCI: PS3.A.2, PS3.B.2; CCC: 2.2)

What to do: If students are struggling to connect the motion of the piston to the increased average kinetic energy of the air particles, use the diagram on **slide S** or the fire syringe to ask them what had to happen for the air temperature to increase. It may also be helpful to share a tennis ball and racket analogy and ask students to think about how the speed of a tennis ball (particle) changes after colliding with a stationary or moving tennis racket. Be sure to tie into ideas of energy conservation. Remind students that we can only trace energy so confidently because we know from *Polar Ice Unit* that it is conserved.

Building toward 3.A.2 Evaluate the impact of the relationship between pressure, volume, and temperature of air (data) on the working model of a diesel engine by identifying energy transfer from the motion of the piston to the air particles in the cylinder as the cause of the temperature increase (effect). (SEP: 4.5; DCI: PS3.A.2, PS3.B.2; CCC: 2.2)

7 · NAVIGATE

4 min

MATERIALS: 3x3 sticky notes, colored markers, science notebook, Driving Question Board

Look back on the day's work. Say, *We started today wondering how just compressing air in a diesel cylinder can make it hot enough to combust injected fuel. We figured out that the moving piston transfers energy to the air particles as it pushes on them to increase their average kinetic energy. So, both gasoline and diesel require an energy input to start burning and they release a lot of carbon dioxide in combustion.*

Add questions to the DQB. Display **slide T** and ask students to add new questions that they have, now that we have figured out more about how gasoline and diesel engines work. Give students a minute to write out their questions and then facilitate adding them to the DQB. If time is running short, you can add students' questions to the DQB at the beginning of the next class.

ADDITIONAL GUIDANCE

When students first built the Driving Question Board in Lesson 1, they may not have had very clear ideas about what is happening in a combustion reaction. The goal of this addition is to elicit more questions at the particle level in the reaction. These questions can be leveraged to aid navigation into Lesson 4 and may include questions about why energy must be transferred into the cylinder system to use any carbon-based fuel, and why we continue to use these fuels when they release carbon dioxide into the atmosphere. Encourage such questions by portraying two ideas as strange: that fuels require an energy input to work, even though we are trying to get energy out, and that these fuels are still used despite being detrimental to the environment. If students do not ask these questions, use the questions they do ask to motivate a more careful focus on what is happening in a combustion reaction.

LESSON 4: Why do we need to put energy into the system to start the reaction?

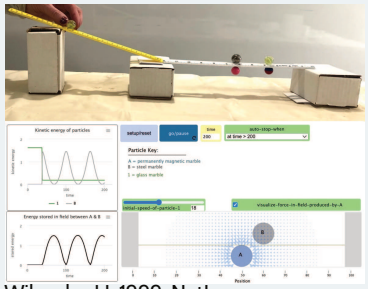
PREVIOUS LESSON

We analyzed trends in air property data and identified qualitative relationships between properties. We used the Combined Gas Law to determine how pressure changes in the fire syringe. We used this approach to determine the pressure needed to combust fuels in a diesel cylinder and explained energy transfer from the piston as the cause of the air temperature increase.

THIS LESSON

INVESTIGATION

2 days



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

We decide to investigate why an energy input was needed to start the combustion reactions of gasoline and diesel fuel. We figure out from the matter perspective that matter is conserved, but we wonder about the energy and forces perspectives. We use magnet marbles to develop ideas about the energy and forces occurring during the reaction. We decide to use a computer model to allow us to quantify the energy and forces in the reaction. We build understanding about what is happening to the reactants during combustion reactions but are still wondering about the products.

NEXT LESSON

We will investigate bond formation using materials similar to those from Lesson 4. We will figure out the changes in matter and energy that occur when a bond forms, update our consensus model, read about two different fuels, and complete an Electronic Exit Ticket to assess our understanding.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

4.A Evaluate the impact of new data on the model of the cylinder system to conclude that changes in matter and energy occur when a bond is broken. (SEP: 4.5; DCI: PS1.B.1; CCC: 5.2)

4.B Develop and revise models based on evidence to illustrate the energy transfers between components of a system to explain why a minimum amount of energy input is required to break bonds of stable reactant molecules in combustion reactions. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1, PS3.C.1; CCC: 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Energy has to be transferred into the field between bonded atoms in order to overcome attractive forces and break them apart.
- If too little energy is added to the system to break the bonds, they will wobble. This wobble is caused by energy moving into and out of the fields of the atoms in the reactant.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Recall what we figured out in our last class and what new questions we had. Consider combustion reactions from a matter perspective.	A-D	
2	12 min		**MAP MANIPULATIVES TO THE CYLINDER SYSTEM** Organize students into partner groups to examine three different marbles. Lead a discussion to map the marbles to matter in the cylinder system.	E-H	1 metal marble, 1 glass marble, 1 magnet marble, chart paper, chart paper markers
3	12 min		**PLAN AND CARRY OUT MARBLE INTERACTIONS INVESTIGATION** Organize students into groups to plan and carry out an investigation using marble manipulatives.	I-J	"Mapping to the Cylinder System" poster, chart paper markers, Marble Interactions Investigation
4	16 min		**MAKE SENSE OF INVESTIGATION DATA** Lead a class discussion to interpret the investigation results. Have students identify forces and energy transfers that occur during the investigation.	K-O	*Energy & Forces*, https://www.youtube.com/watch?v=GD1p-2CtuVU, internet-connected device, projector with sound, M-E-F poster, "Mapping to the Cylinder System" poster
					End of day 1
5	4 min		**NAVIGATE** Have students turn and talk with a partner to compare models and identify differences between the two results modeled.	P	*Energy & Forces*, "Mapping to the Cylinder System" poster
6	17 min		**USE A SIMULATION TO QUANTIFY ENERGY TRANSFER** Show https://youtu.be/MNygD-xgD08 to orient students to the computer model. Have students individually plan and carry out an investigation using https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR.html.	Q-T	https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR.html, internet-connected device, "Mapping to the Cylinder System" poster, chart paper markers, https://youtu.be/MNygD-xgD08, projector with sound
7	17 min		**BUILD UNDERSTANDING OF INVESTIGATION DATA** Gather students in a Scientists Circle to share their investigation findings. Connect investigation findings to the cylinder system model.	U-Z	*Mapping Between Models*, *Energy Graphs*, *Mapping Between Models Key*, M-E-F poster, chart paper, chart paper markers
8	7 min		**NAVIGATE** Have students complete an exit ticket mapping their new understandings back to the cylinder system.	AA	
					End of day 2

Lesson 4 • Materials List

	per student	per group	per class
Marble Interactions Investigation materials	• science notebook • safety glasses with side shields	• 1 metal marble • 1 glass marble • 1 ruler • 3 box stands • clear tape	
Lesson materials	• science notebook • *Energy & Forces* • https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR.html • internet-connected device • *Mapping Between Models*	• 1 metal marble • 1 glass marble • 1 magnet marble • *Energy Graphs*	• chart paper • chart paper markers • "Mapping to the Cylinder System" poster • https://www.youtube.com/watch?v=GD1p-2CtuVU • internet-connected device • projector with sound • M-E-F poster • https://youtu.be/MNygD-xgD08 • *Mapping Between Models Key*

Materials preparation (120 minutes)

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

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

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

You will be preparing equipment for investigations using magnet marbles for Lessons 4-7. Use *Building Marble Equipment* as a guide to prepare all of the materials needed for all of these lessons now, using the equipment contained in your unit supply kit.

Have the M-E-F poster available.

On day 2, students may use either of two computer models.
- The default simulation focuses only on *total* kinetic energy and energy in the field: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR.html
- The alternate simulation includes information about the kinetic energy of each particle: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR+expanded.html

Test both of these. You may choose to leverage either or provide students an option. The first time through, you may wish to provide all students with the simplified simulation, then give students the option of the alternate simulation to help answer questions they might have.

Day 1: Marble Interactions Investigation
- **Group size:** 5 students
- **Setup:** Prepare materials using *Building Marble Equipment*.
- **Notes for during the lab:** Ensure that students do not lose any of the marbles, as these can be a falling hazard if left on the floor. It is recommended that you set up a box or tray for catching the marbles.

- **Safety:** Ensure that students do not attempt to open the magnet marbles. Students could pinch their fingers or experience health emergencies if the magnets are swallowed. Pick up any marbles off the floor to prevent trip/slip fall hazards. Make sure there are not fragile items in the projectile trajectory zone. Wear sanitized safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of the activities. Wash hands with soap and water after completing the activity.
- **Disposal:** Do not dispose of any materials.
- **Storage:** Store all materials in a cabinet for future use.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.A.4 Structures and Properties of Matter:** Stable forms of matter are those in which the electric and magnetic field energy is minimized. 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.
- **PS1.B.1 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.~~
- **PS3.C.1 Relationship Between Energy and Forces:** When two objects interacting through a field change relative position, the energy stored in the field is changed.

Crossout explanations: Students investigated reaction rates in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. They will examine changes in net bond energy in Lessons 6 and 7.

Students' work in prior units helped to develop understanding about energy conservation in collisions and energy transfer to and from electric fields:

- In *Polar Ice Unit*, students calculated differences in particle-level kinetic energy (as measured by temperature) as energy was transferred between different amounts of matter in particle collisions.
- In *Electrostatics Unit*, students incorporated field thinking to energy conservation. They used a computer model that illustrated changing amounts of kinetic energy and energy stored in the field as a particle moved through space.
- In *Oysters Unit*, students examined the impact of temperature changes on reaction rates. Call back to this experience to help explain the energy input required to cause a reaction to occur.
- In *Fuels Unit*, students' level of sophistication increased because of the use of multiple particles moving through space, resulting in changes to the amount of energy stored in the field and the kinetic energy of the particles. References to those experiences and models they developed in prior units are leveraged in this lesson and extended in Lessons 5-8.

Students examine two *combustion reactions* to consider what has to *happen to the reactant molecules before the product molecules can be formed* (DCI: PS1.B.1; CCC: 5.2). They investigate "bonds" between reactant molecules using magnet marbles. This *new data* allows students to *evaluate* the relationship between *breaking bonds and energy transfer in their model* (SEP: 4.5; CCC: 5.2). They use data from the magnet marble investigation to *develop initial models* to explain their results in terms of changes in matter, energy transfer, and force interactions (SEP: 2.3; DCI: PS1.B.1, PS3.C.1). This draws on students' work in explaining phenomena using the M-E-F poster they foregrounded in the last three lessons.

Students then use a computer model to collect additional *data to evaluate their energy transfer models* (SEP: 4.5). They use their investigative data to *determine the minimum amount of energy transfer needed to break the bond between reactants* (DCI: PS1.A.4; CCC: 5.2). The whole class ties this thinking together as they revise the "As opposite charges move apart from each other" poster from *Electrostatics Unit*. Students apply this *model to explain energy transfers in the marble system when the marbles do not separate* (SEP: 2.3; DCI:PS1.B.1).

Where We Are NOT Going

Students will record quantitative information about energy transfers needed to break a bond. At this point, do not have them consider net bond energy released from the combustion reactions.

The ideas of net bond energy changes as a result of reactions, and *exothermic reactions*, are developed over the course of Lessons 4-8. In Lesson 5, students will focus on energy transfers and changes during bond formation. In Lesson 6, students qualitatively identify differences in energy inputs and outputs as a result of breaking and forming bonds. In Lesson 7, students compare the bond strengths of atoms in both product and reactant molecules using electronegativities and magnet marbles. They quantify these differences and develop a definition of *exothermic reactions*.

We do not refer to energy stored in fields as potential energy in this lesson, besides a reference in Lesson 11 to mirror the language of the simulation. Potential energy is parenthetically used when citing examples of energy stored in gravitational, electric, and magnetic fields in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Academies Press, 2012). While you might introduce the term parenthetically as well, using it in the classroom may lead to misconceptions, such as:

- associating potential energy with an object rather than a system of objects that produces a field; or
- thinking of it as a form of energy, rather than focusing on the field as an important part of the system that can store and transfer energy.

For more information about how energy is framed throughout this course, see *Energy Anchor Chart* from *Polar Ice Unit* and *Matter, Energy, Forces* from *Electrostatics Unit*.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

5 min

MATERIALS: None

Think back to what we figured out last class. Display **slide A** and lead students in discussion of the prompts.

Suggested prompt	Sample student response
What have we figured out so far about gasoline, diesel, and other carbon-based fuels?	How different kinds of engines work. Where the CO_2 comes from when these fuels are burned. That you need energy to start it, and energy comes out.
What questions did we have at the end of the last lesson?	Why do you need energy for something to spark or the fuel to burn? What is happening exactly when the substances react?
How might answering those questions help us think about our future transportation system?	We would better understand how carbon-based fuels work, so we know what it takes to improve or replace them. We will better understand why we are currently using fuels that release so much carbon dioxide.

Consider why energy might be needed for a reaction. Display **slide B**. Say, *It sounds like one of the big mysteries is what, exactly, is going on with that energy input – the spark or the compression. Turn and talk with a partner about the prompts on the slide.* Give students a couple of minutes to discuss the prompts with a partner before asking for volunteers to share. As students share their ideas, accept all responses.

Suggested prompt	Sample student response
Think back to prior units. Where else have we seen energy input needed to start a reaction or other process? Why was that?	Polar Ice Unit – energy sped up ice particles, causing them to melt. Oysters Unit – reactions happened faster at higher temperatures because the particles collided more and were able to break bonds more.
Why do you think we have to put energy into the cylinder system to get the fuels to react with oxygen?	Maybe because it is causing bonds to break. The particles need to be hotter so they can react.

Suggest that zooming in on what is happening with the fuel molecules might help us answer some of our questions about why energy is needed to start combustion reactions.

Consider the combustion reactions from a matter perspective. Say, *So a lot of your responses talked about energy moving into the system to help get the molecules to move, or change in some way. Let's consider a matter perspective.* Display **slide C**. Say, *Look at the structural representations for the gasoline and diesel combustion reactions. What is happening on each side of these equations?* Look for students to say that octane or dodecane (doh-DECK-ane) is combining with oxygen gas to form water and carbon dioxide.

Ask, *What needs to happen to these reactant molecules before the products can be formed?* Look for students to suggest that they need to break apart, or that bonds between atoms need to break. Suggest that because bonds have to break in a reaction, this may connect to the energy input somehow.

Zoom in on the bonds. Display **slide D**. Ask, *What is happening in a bond between two atoms?* Listen for these ideas:

- There is an attractive force between the atoms.
- The atoms pull on each other.

Elicit ideas about what bonds might have to do with the energy input. Accept all responses.

2 · MAP MANIPULATIVES TO THE CYLINDER SYSTEM

12 min

MATERIALS: science notebook, 1 metal marble, 1 glass marble, 1 magnet marble, chart paper, chart paper markers

Identify components and interactions we need to explain why combustion reactions require an energy input to start. Display **slide E**. Point out that in prior units we figured out why different types of atoms bond with other atoms. Read the prompts on the slide and give students a couple of minutes to stop and jot their ideas.

Suggested prompt	Sample student response
What parts or components of the atom did we use to help us explain bonding?	Electrons and protons because they attract.
What interactions between those parts helped us explain bonding?	Opposite charges between the electrons and protons. The numbers of valence electrons in each atom.
What representations have we used to help us understand bonding?	Paper-clip models. Drawings of molecular structures. Simulations.

Problematize that the paper-clip models make it difficult to show particles moving around a lot, like they do in the cylinder system. Suggest that another model might be more useful to us in this scenario. Say that you thought marbles might be helpful for modeling, since they move around easily, and elicit student ideas about what they could represent in the cylinder system. Accept all responses.

Prepare to use a physical model to explain why an energy input is required for a combustion reaction to occur. Display **slide F** and have students read the sentence at the top of the slide. Organize students in pairs and distribute three marbles to each group: 1 glass, 1 metal, and 1 magnet.

Introduce the three marbles to the class. Leverage student suggestions that the marbles represent atoms or molecules, but suggest that different marbles might be useful to model different particles. Then, read the instructions on the slide. Ask students if they have any clarifying questions before they begin their investigations.

Start to map the marbles to the matter in the cylinder system. Display **slide G**. Say, *Let's take a minute to share what you figured out using the different marbles with your partner.* Ask the questions on the slide:

- Which two marbles did you choose?
- Which bond in a reactant molecule could these marbles represent?

As students share, note their ideas on a piece of chart paper. Leave space at the top of the chart to add the investigation question. A sample chart is shown.

Mapping to the Cylinder System	
Marble System Metal marble and magnet marble bond together.	Cylinder System C-C, C-H, or O=O bond

Add non-bonding substances to the chart. Ask, *What other matter could the glass marble represent in the cylinder system?* Look for students to name other types of gases in the system.

If students do not mention gases, elicit ideas about how the glass marbles are different--that they cannot bond to anything else. Have students think about whether there are any substances in the cylinder system that are not involved in the reaction. Add students' ideas about non-reacting air or gas particles to the chart.

Mapping to the Cylinder System	
Marble System Metal marble and magnet marble bond together. Glass marble	Cylinder System C-C, C-H, or O=O bond Other gas particles in the cylinder system

Shift to an energy perspective. Remind students of the energy transfer model they developed in Lesson 3, with energy input coming from a spark or compression causing particles to speed up. Elicit ideas about how we could similarly speed up a marble in our physical model reaction.

Continue to map to the cylinder system using the investigation setup. Display **slide H**. Orient to where the magnet marble is located on the underside of the ruler in the diagram, emphasizing that the track between them is thin enough to permit the metal marble to be bonded to the magnet marble below it. Also emphasize that the track ensures a way to control the path of the marbles so that we can carry out controlled tests of the system.

Ask students, *How can we use this setup to transfer different amounts of energy into the cylinder system with the glass marble?* Look for students to say that you can release the marble from different heights.

Mapping to the Cylinder System	
Marble System Metal marble and magnet marble bond together. Glass marble Energy input - Glass marble release height on ramp	Cylinder System C-C, C-H, or O=O bond Other gas particles in the cylinder system Energy input - Speeding up air particles (with a spark or by compression)

Highlight the question this setup will allow us to investigate. Say, *This investigation setup should allow us a way to explore what happens to bonded particles when different amounts of energy are transferred to them.* Add this question to the top of the chart paper. Leave this "Mapping to the Cylinder System" poster visible for the duration of the lesson. It may also be helpful to display it during Lessons 4-7.

What happens to bonded particles when different amounts of energy are transferred to them? Mapping to the Cylinder System

Marble System	Cylinder System
Metal marble and magnet marble bond together. Glass marble Energy input - Glass marble release height on ramp	C-C, C-H, or O=O bond Other gas particles in the cylinder system Energy input - Speeding up air particles (with a spark or by compression)

ADDITIONAL GUIDANCE

"Particle" language is intentionally emphasized in this task to support connections between the ideas of bonds breaking in molecular compounds and similar energy transfers in dissolution and other processes that are not chemical reactions.

3 · PLAN AND CARRY OUT MARBLE INTERACTIONS INVESTIGATION

12 min

MATERIALS: Marble Interactions Investigation, "Mapping to the Cylinder System" poster, chart paper markers

SAFETY PRECAUTIONS



Ensure that students do not attempt to open the magnet marbles. Students could pinch their fingers or experience health emergencies if the magnets are swallowed. Pick up any marbles off the floor to prevent trip/slip fall hazards. Make sure there are not fragile items in the projectile trajectory zone. Wear sanitized safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of the activities. Wash hands with soap and water after completing the activity.

Introduce investigation design. Gather students into small groups and display **slide I**. Say, *Now that we have our investigation question and the investigation setup and materials available, work with your groups to plan an investigation to gather data to answer the investigation question: What happens to bonded particles when different amounts of energy are transferred to them? Once you have completed your group's investigation plan, share it with me before you carry out the investigation.*

Give groups about five minutes to plan their investigations and share them with you. Provide feedback to groups during and after the development of their investigation plans.

If a group's investigation plan does not outline the number of tests they will conduct to measure energy, use a prompt such as:

- How many different amounts of energy do you want to try to transfer into the system?

If a group does not clearly identify the data they will collect to help answer the investigation question, use a prompt such as:

- Are there any measurements you want to take or do you want to keep your observations qualitative?

Carry out investigation plans. Display **slide J**. Give groups about five minutes to carry out and record data from their investigations. As groups carry out their investigations, circulate around the room and ask students about the movement of the magnet and metal marbles when they do not break apart. Highlight that the two marbles do not always come apart, but that there is still some movement back and forth when the glass marble makes contact with the metal marble.✱

✱ ATTENDING TO EQUITY

Universal Design for Learning: The ruler and marble physical model connects students' everyday experiences of a magnet's forces (*perception*) to how a bond works at a distance. Allowing students the time to experience the physical, tactile "pull" of magnets and how hard you have to "knock" them to get them to come apart is very important for equitable sensemaking, as it allows students to bridge their everyday schema to scientific concepts like bonds. We recommend that you do not skip this activity, as it provides an equitable, human-scale experience that will benefit all students, including emerging bilingual students, students with disabilities, and even gifted and talented-identified students.

ALTERNATE ACTIVITY

Some students may benefit from watching videos of the investigation. Two videos can be used to help students:

- https://www.youtube.com/watch?v=RgdkTcHg2c8, a real-time video of the investigation
- https://www.youtube.com/watch?v=GD1p-2CtuVU, a slow-motion video of the investigation

4 · MAKE SENSE OF INVESTIGATION DATA

16 min

MATERIALS: science notebook, *Energy & Forces*, https://www.youtube.com/watch?v=GD1p-2CtuVU, internet-connected device, projector with sound, M-E-F poster, "Mapping to the Cylinder System" poster

Evaluate the impact of new data. Display **slide K**. Give students a few minutes to discuss the prompts in their groups before discussing them as a class.

Suggested prompt	Sample student response
How did changing the amount of energy you transferred into the marble system affect the outcome?	More energy (or higher release point) caused the marbles to break apart. Less energy (or lower release point) did not cause the marbles to break apart, but they still moved a little.
What data did you use to come to your answer?	Whether the marbles broke apart or not. The release height for the marble on the ramp.
How does this new data affect your understanding of the cylinder system?	It just confirmed our ideas that energy helps break the bonds. We wonder if there are real-life situations where an energy input isn't enough to break the bonds.

Leverage uncertainty about situations where the bonds do not break to motivate adding a forces lens, alongside the energy lens.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use investigation data to describe where energy transfers and matter changes occur in the system. (SEP: 4.5; CCC: 5.2)
- Students identify that collisions between particles can lead to rearrangements of atoms, or the breaking of bonds. (DCI: PS1.B.1)
- Students tie their new data back to energy flows in the cylinder system. (SEP: 4.5; CCC: 5.2)

What to do: If students did not identify that a collision results in breaking bonds, invite them to try to determine just how high the glass marble needs to be to break the bond. Encouraging students to go back to the manipulatives may help them identify the connection between release height, energy transfer, and matter changes (bonds breaking). If students are talking in terms of marbles and rulers, encourage them to transfer their everyday knowledge about marbles to bonds and energy by using the "Mapping to the Cylinder System" poster.

Building toward 4.A.1 Evaluate the impact of new data on the model of the cylinder system to conclude that changes in matter and energy occur when a bond is broken. (SEP: 4.5; DCI: PS1.B.1; CCC: 5.2)

Identify where the forces and energy are in the marble system. Display **slide L**. Distribute *Energy & Forces*. Say, *Let's take a minute to think about where the forces and energy are in the marble system. On the handout, there are two different models for you to complete to identify where forces and energy are transferred in the marble system. Let's begin by modeling the first result, where the bond broke between the magnet and metal marbles.* Give students four minutes to individually complete the model for Result 1 on *Energy & Forces*.

As students work on their models, choose a few that show differences in how and where they identified the energy and forces. These will be shared with the class to help students think about different parts of the process. You may choose to cover students' names, or ask students to talk about their thinking.

ADDITIONAL GUIDANCE	Have the M-E-F poster available for students to view as they develop these two models. This will help students tease apart areas where forces and energy transfer overlap in the moment of the particle (glass marble and metal marble) collision.

Display the student models you chose. Name these as "collision models" and have students take a moment to examine and discuss how they compare.

Suggested prompt	Sample student response
What similarities do you see?	They have the same components and interactions. The glass marble hits the metal marble, breaking the bond.
What differences do you see?	Some people labeled a force transfer and some labeled an energy transfer when the glass marble hits the metal marble.

Recall that forces transfer energy. Leverage student responses that show disagreement about force and energy transfer labels. Refer back to the M-E-F poster to point out the relationship between forces and energy transfers. Ask, *How does the relationship between forces and energy help explain the differences in the models?* Look for students to suggest that forces transfer energy from one object to another. Say, *Great! Let's consider another result some of you mentioned, when the bond was not broken.*

Consider when the bond does not break. Display **slide M**. Say, *Some of you said that the metal marble wiggled, or moved, but did not separate from the magnet marble when the glass marble hit it. I have a slow-motion video that might help us observe this result more closely.* Show https://www.youtube.com/watch?v=GD1p-2CtuVU. Encourage students to record observations in their science notebooks. After showing the video, ask students what they noticed. Look for students to mention that the metal marble wiggled for a little while before coming to a stop.

Display **slide N**. Say, *Take a moment to develop a model to explain this other result in terms of forces and energy.* Give students four minutes to individually develop a model for Result 2, in which the bond does not break. As students complete their models on the handout, choose two or three examples that show different levels of uncertainty about the amount of energy or forces being applied to the metal marble. Students may represent this by changing the force shown on either the glass or metal marble, or by showing less energy transfer from the glass marble to the metal marble.

Debrief as a class. Display **slide O.** Show the example collision models and have students take a few moments to examine them. Use the prompts to help students clarify their thinking.

Suggested prompt	Sample student response
What do you notice is different in these models compared to the first models?	They have less force applied and energy transferred to the metal marble. There is less energy on the glass marble.

Suggested prompt	Sample student response
How do these differences help explain the different results?	There wasn't enough energy transferred to the metal marble to break the bond. The forces were too strong for the bond to break without enough energy input into the system .
How much energy is required to break the bonds?	I'm not sure, we couldn't measure it.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models include changes (speed and position) in the particles (matter) at different points of time in the system. (SEP: 2.3; CCC: 5.2)
- Students' models include changes in energy (kinetic energy of particles and/or energy stored in the field) at different points of time in the system. (SEP: 2.3; DCI: PS1.B.1)
- See *Energy & Forces Key* for additional information.

What to do: If students do not begin to consider that there is a minimum amount of energy transfer required, invite them to try to determine just how high the glass marble needs to be to break the bond. Encouraging students to go back to the manipulatives may help them identify the connection between release height, energy transfer, and minimum amounts of energy needed to break the bond.

Building toward 4.B.1 Develop and revise models based on evidence to illustrate the energy transfers between components of a system to explain why a minimum amount of energy input is required to break bonds of stable reactant molecules in combustion reactions. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1, PS3.C.1; CCC: 5.2)

End of day 1

5 · NAVIGATE

4 min

MATERIALS: *Energy & Forces*, "Mapping to the Cylinder System" poster

Compare models for the different results. Display **slide P.** Give students two minutes to discuss the prompts on the slide.

Then ask students to share some of the differences that they discussed. Accept all responses, but sample ideas are shown.

Suggested prompt	Sample student response
What are the differences between the models for Result 1 and Result 2?	In Result 2, the bond doesn't break. There isn't enough energy in Result 2. In Result 1, the force from the magnet can't withstand the glass marble coming in.

Suggested prompt	Sample student response
What would each result mean if something like it happened in the cylinder system?	Result 1 is like a normal spark and engine firing. Result 2 is like it failed, misfired, or backfired.

After a couple of minutes, transition to thinking about force ideas. Say, *It sounds like the ideas we have on our M-E-F poster related to forces transferring energy are also a part of our explanations here. If both energy transfers and force interactions are part of our explanations, then what remaining questions or areas of uncertainty do we have about what is happening in the system in terms of forces or energy?*

Accept all responses, but listen for questions like:

- How much force is there in the system at different points?
- Is there a minimum amount of energy it takes to break a bond?
- How much of the energy is transferred into breaking the bond versus staying with the particles that collide with each other?

Identify an emerging theme in students' questions. Highlight questions that show uncertainty around amounts, and suggest that when we struggle to measure a quantity like energy, in the past we have turned to computer models.

6 · USE A SIMULATION TO QUANTIFY ENERGY TRANSFER

17 min

MATERIALS: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR.html, science notebook, internet-connected device, "Mapping to the Cylinder System" poster, chart paper markers, https://youtu.be/MNygD-xgD08, projector with sound

Consider data we need to quantify energy transfer in a computer model. Display **slide Q**. Read the related description at the top of the slide. Then discuss the prompts and as students share, record their answers on the board.✱

Suggested prompt	Sample student response
What additional measurements or visualizations would we want a simulation to provide?	How strong the forces are at different points in space. Maybe the direction of those forces too. How much (kinetic) energy each marble has at different points in space (or at different points in time). Graphs of these measures. A way to visualize the forces (like we saw in the sims in Electrostatics Unit).
What parts and interactions would we need included in a simulation of the system we explored last class?	Three marbles or different types of atoms/molecules. Attraction between two of the atoms. Collision between marbles. A track. A ramp or another way to give the glass marble different speeds before the collision with the other marble.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This moment in the lesson calls for students to integrate the three dimensions deeply: computer-based models, energy and matter thinking, and physical science ideas about bonding. You may make these different dimensions explicit to students.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Giving students choice around which set of their questions they want to try to answer using the computer model supports *engagement* with the 3D standard in two ways: (1) Recruiting interest is activated by allowing for student choice; (2) Self-regulation is supported later in this step by students working independently to develop their investigation plans.

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Introduce and evaluate the simulation. Display **slide R**. Say, *Let's take a moment to evaluate whether the simulation we have available includes our top needs. As you watch the simulation, make a mental note of which of our top needs are and are not addressed by the simulation.*

Show https://youtu.be/MNygD-xgD08. Then ask, *Can we agree that the simulation has many of the things we need?* Students can verbally agree or give nonverbal signals to show agreement. Take a moment to update the "Mapping to the Cylinder System" poster to add the simulation information.

What happens to bonded particles when different amounts of energy are transferred to them? *Mapping to the Cylinder System*	
Marble System & Simulation *Metal marble and magnet marble bond together.* *Particle Me Particle Ma* *Glass marble - Particle G* *Energy input - Glass marble release height on ramp - initial speed of Particle G*	*Cylinder System* *C-C, C-H, or O=O bond* *Other gas particles in the cylinder system* *Energy input - Speeding up air particles (with a spark or by compression)*

Plan investigations to gather data we need from the simulation. Display **slide S.** Say, *Choose an area on either model where you have a lot of questions.✱ Consider how you could use the simulation to gather data to help you make progress on at least one of those questions, by designing an investigation plan. Use the prompts on the slide to help guide the development of your investigation plan.✱* Give students about five minutes to individually plan their investigations using https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR.html.
Carry out investigations. Display **slide T**. Give students eight minutes to carry out their investigations and record associated data.

If investigation plans do not identify the types of data needed to answer their questions, refer students to the prompts on **slide S**. Ask students to use those prompts to help clarify how much and what types of data they will need. If students do not collect data in a manner that will aid in answering their questions or that is not accurate, prompt them to revise their data tables or go back to the simulation to collect more precise data.

ALTERNATE ACTIVITY

If students express that it would be useful to know more about energy at the particle level, provide the alternate simulation: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+Bonds+PR+expanded.html.

If students finish early, encourage them to explain how their investigation data helped them answer their questions. This could also be assigned as home learning. By adding this extension activity, you could also formatively assess students' understanding of the following **look/listen fors** a second time using a different modality (first assessed verbally on **slide K**):

- Students use investigation data to describe where energy transfers and matter changes occur in the system. (SEP: 4.5; CCC: 5.2)
- Students identify that collisions between particles can lead to rearrangements of atoms, or the breaking of bonds. (DCI: PS1.B.1)

Students have practiced collaboratively designing investigations throughout the chemistry course. Having students individually design investigation plans to answer their questions about a model increases the level of sophistication with which students are engaged in this practice. Support students while they are responsible for their own investigation designs. Use clarifying questions to help them be explicit about how they will use the simulation to answer their questions about specific areas of their model of choice.

7 · BUILD UNDERSTANDING OF INVESTIGATION DATA

17 min

MATERIALS: *Mapping Between Models*, science notebook, *Energy Graphs*, *Mapping Between Models Key*, M-E-F poster, chart paper, chart paper markers

Interpret investigation data to make sense of energy transfers. Have students bring their notebooks to meet in a Scientists Circle.✱ Display **slide U**. Discuss this question as a class to establish the range of results that were in common across investigations: *How did changing the amount of energy you transferred into the marble system affect the results?* Accept all reasonable responses, and if something surprises you, have the students show how they obtained that result.

Look for students to say:

✱ ATTENDING TO EQUITY

Students should speak to each other during a Scientist Circle. If you find you are interrupting or managing the conversation

- The bond broke with an initial Particle *G* speed above 30.
- The bond did not break if the initial speed of the marble (energy) was below 30.
- When the bond did not break, it wobbled back and forth, and the less energy we transferred into the system the less distance it wobbled over.

If students do not see how the marble wobbles in the simulation, set the "auto-stop-when" dropdown menu to "when *G* & *Me* leave the system" and demonstrate this behavior.

Connect kinetic energy changes to energy input and output in the system. Ask, *How did the amount of kinetic energy of each marble change over time?*
Look for students to say:
- Particle *G*'s kinetic energy was higher before the collision.
- If students modeled the bond breaking:
    - Particle *Me* had more kinetic energy after the collision (it was zero before it).
    - The total kinetic energy dropped with the collision, while the total energy in the field increased.
- If students modeled the bond **not** breaking:
    - Kinetic energy seemed to go up and down after the collision and Particle *Me* wobbled back and forth.✱

Elicit initial ideas about the energy transfers that occurred. Display **slide V**. Distribute a copy of *Energy Graphs* to each pair of students and display the M-E-F poster.

Have students identify, by tracing over it with their finger, the part of the Result 1 graphs that provides evidence that the kinetic energy of the particles continued to change even after the collision. Ask, *What is causing the total kinetic energy to decrease after the collision?*
Look for students to say:
- The bond.
- Attractive forces between the particles.

Shift students' focus to the collision. Elicit students' ideas about why the total kinetic energy dropped when the collision occurred. Students may suggest that energy was transferred into the field, or they may be uncertain.

Leverage any uncertainty to ask students when we have explored energy in particle interactions before. Students may recall simulations in *Electrostatics Unit*; if they do not, remind them that this was where they originally developed ideas about energy transfers in static interactions. You may also wish to briefly demonstrate https://lab.concord.org/embeddable.html#interactives/interactions/amount-charge.json to remind students of that simulation. Gain student agreement that there might be some parallels between that situation and this one that would be helpful to map out.

Introduce the mapping task. Display **slide W** and distribute *Mapping Between Models*. Remind students of the energy transfer model they developed from the simulation of charges in a field and suggest that we might see similar energy and matter behavior in this situation.

Provide time to map between charges in a field and bond breaking. Have students work with a partner without breaking the Scientists Circle. Use *Mapping Between Models Key* to provide guidance. It is okay if not every student is clear on every idea, as understandings will be solidified in the Building Understandings Discussion. If students are not identifying that as the bonded atoms start to move apart the amount of energy stored in the field between them increases, ask them to refer back to the stored energy graphs in *Energy Graphs*.

too much, remind students of their collective purpose in this activity: figuring out patterns in kinetic energy in this bond-breaking system.

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

If this is difficult for students, ask them to talk to a partner about what the graphs for their marbles did, before students come back to the whole group. Give students responsibility for making sense of the computer model themselves; do not interpret it for them. This is the first time students have had to make sense of bonds breaking in terms of energy, so it is worth the investment of time to help students' confidence grow.

KEY IDEAS

Purpose of this discussion: To develop an energy transfer model that explains why energy is required to break a bond in either the computer model or marbles physical model. Students will have the opportunity to apply their energy transfer model to the cylinder system at the end of the discussion.

Listen for these ideas:

- Bonded particles lose kinetic energy as they move farther apart.
- As particles move farther apart, energy transfers into the field. The energy in the field is lowest in a bonded molecule.
- Energy is initially transferred into the system through collision by an outside particle and is needed to break bonds in the system.

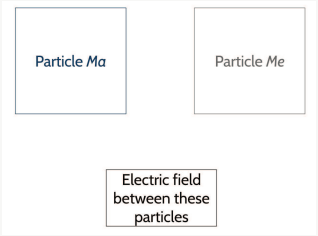
Remind students throughout that boxes represent components of the system (objects or fields), arrows represent energy transfers, and parenthetical text indicates what happens to an object when energy is transferred to or from it. Encourage students to revise their own energy transfer model on *Mapping Between Models* as they help build the class model.

Build a class energy transfer model. Display **slide X.** Begin by asking students what components of breaking bonds in the simulation are equivalent to those in the older energy transfer model. Students should say:

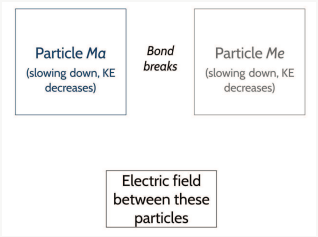
- Particle *Me* (metal marble)
- Particle *Ma* (magnet marble)
- The electric field between these particles (or the magnetic field between atoms)

Have students tie any mentions of the physical marble system to the simulation, to promote transfer to the particle level.

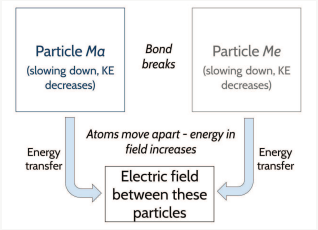
Add the three components the class just agreed on to a blank piece of chart paper.



Elicit ideas about what this model is actually showing. Once students have agreed that it represents bonds breaking, label the model as such. Then ask, "What happens to Particles Me and Ma when the bond breaks?" Students should readily recognize that after initially speeding up, Particle Me slows down. Add this idea to the model. If students are less sure about Particle Ma, use a "bonded" metal marble and magnet marble that are not attached to a ruler to demonstrate that if they are moving, they slow down when their bond is broken by a glass marble.



Ask, “Where is the energy transferring to in this system?” Look for students to suggest into the electric field. Add arrows with the label “energy transfer” to indicate what the arrows represent. Then ask, “How does the movement of the two atoms change the stored energy in the field?” Look for students to suggest that as the atoms move apart, the energy stored in the field increases. Add that annotation to the model.



Tie energy in the field to bonding. Ask students, *When did we see the energy in the field at its lowest? Why was that?* Students should suggest that energy in the field was lowest before the collision, when the atoms were still bonded and before kinetic energy was transferred to the atoms.

ALTERNATE ACTIVITY

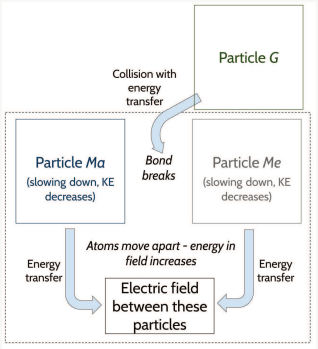
Extension opportunity: Here, students are able to add some nuance to their definition of bonding. You may extend this discussion by leveraging the crosscutting concept of *stability and change* to ask students how energy was different in a stable molecule compared to unbonded particles moving around. In Lesson 6, students will see complete, simplified energy coordinate diagrams, so do not take them there yet, but if students establish that a stable molecule has a lower energy in the field than separate atoms, you may have students add this nuance to their existing definition of *bond* from prior units.

ADDITIONAL GUIDANCE

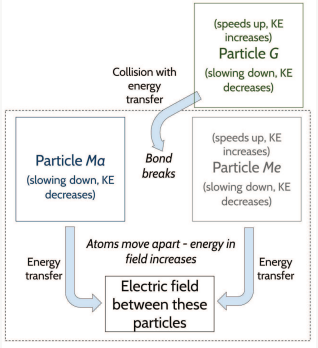
If students ask about whether the shared electrons should also be added to this model, compliment the critique and suggest that students add this question to the Driving Question Board. Point out that scientists try to use the simplest model that answers their question, so we can add the subatomic level to our model if we decide that it is no longer able to answer our questions. Be sure to return to this question in Lesson 8 to decide as a class whether a subatomic-level understanding is necessary to explain the energy transfers we observe.

Add the initial energy input to the model. Display **slide Y.** Use the prompts to guide students toward adding energy input to the model.

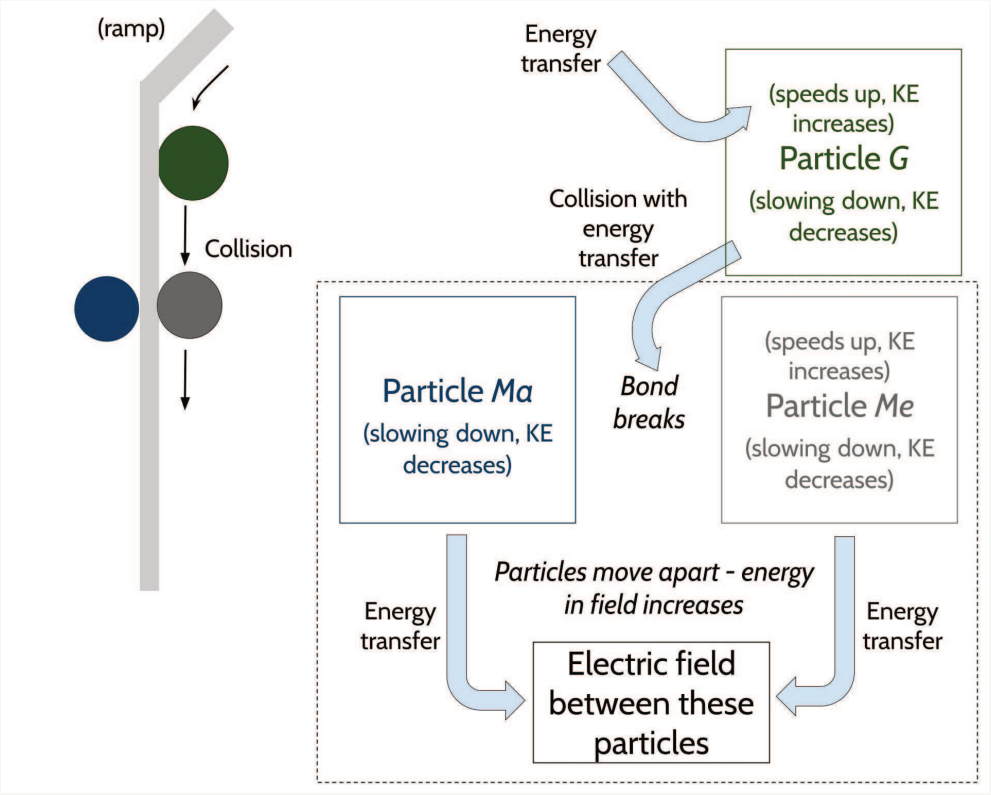
Point out that the model right now only represents what is happening as the bond is breaking. Ask students, “How did we transfer energy into the system?” Add a dotted line around the system. Students should say that we used a sped-up particle (Particle G) or a ramp and glass marble, and that the particle collided with one of the bonded atoms. Add a box labeled “Particle G” outside of the system.



Ask students, "What happens to the kinetic energy of Particle G when it collides with Particle Me?" Students will say that some of the energy is transferred and the kinetic energy of Particle G decreases. Add an arrow showing the energy transfer, and the word "collision" and annotated text shown in the Particle Me and Particle G box.



Trace the energy back further. Ask, *Where did Particle G get its energy from?* Look for students to say that the energy came from the ramp. It is okay for students to mention a spark or compression. At this point, do not add it to the model as students will map back to the cylinder system later. If students would benefit from explicitly showing references to the marble system, add them as shown below.



Re-emphasize the energy input-bond breaking relationship. Ask, *What is the purpose of that energy input?* Listen for the idea that it is needed to break bonds in the system. If students do not recognize this idea, ask them to trace the effects of the initial energy input in the model that the class just developed.

Evaluate the usefulness of the model. Ask, *How does this model help us explain why it takes a certain amount of energy to break a bond?* Look for students to suggest that you have to transfer enough energy into the electric field to move the atoms far enough apart so they are no longer bonded. If students do not reach this conclusion, encourage them to compare the atoms when they are bonded to when they are not bonded, so they recognize distance as a key difference.

ADDITIONAL GUIDANCE

Particularly if students wanted to bring electrons into their model earlier in the lesson, ask, *Why would the atoms need to be a certain distance apart in order to not be bonded? Does it have anything to do with the subatomic particles involved in bonding?* Give students time to discuss, and they should recognize that attraction decreases at a distance and covalently bonded atoms lose the ability to share electrons.

Use the energy transfer model to explain Result 2. Suggest that if we have a strong model, we should be able to generalize it to explain why bonds do not break in some situations. Display **slide Z**. Have students turn and talk with a partner about the prompt on the slide. After a few minutes, ask for a few volunteers to share their discussion. Listen for these ideas:

- The energy transfer from Particle *G* to Particle *Me* will be smaller if the bond isn't going to break.
- Energy will not just go from Particles *Me* and *Ma* to the field. It will also go back and forth.

Retain the "Bonds Breaking" poster as it will also be used in Lesson 5.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models show revisions that reflect evidence gathered from the simulation. (SEP: 2.3)
- Students identify that when one particle interacting through a field changes its relative position to another particle it is attracted to, the energy stored in the field changes. (DCI: PS3.C.1; CCC: 5.2)
- Students identify a minimum amount of energy transferred into the system for breaking the bonds of reactant molecules. (DCI: PS1.A.4; CCC: 5.2)

What to do: You may collect students' *Mapping Between Models* and provide complimentary feedback on their initial models, as well as probing questions about the evidence that supported changes they made to their energy transfer model throughout the class discussion. Also leverage canonical responses to prompts about energy transfer and forces to provide the basis for probing questions that help students recognize energy transfers they had initially missed when working in pairs.

Building toward 4.B.2 Develop and revise models based on evidence to illustrate the energy transfers between components of a system to explain why a minimum amount of energy input is required to break bonds of stable reactant molecules in combustion reactions. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1, PS3.C.1; CCC: 5.2)

8 · NAVIGATE

7 min

MATERIALS: science notebook

Apply the model to the cylinder system. Display **slide AA**. Say, *We have spent a lot of time modeling what is happening to both the marbles and the atoms in molecules as the bonds between them break. Let's map this back to what is happening in the cylinder system that we have been examining.* Give students the remainder of class to complete the exit ticket. Tell students that they may be unsure of the third prompt in particular, and that their best idea is fine.

1. What do our new data tell us about why a certain amount of energy needs to be transferred into the cylinder system to start the reaction?
2. What happens after this initial energy input?
3. Do our data from this lesson explain why we continue to use carbon-based fuels even though they release CO_2?

4. How confident are you in using data and thinking about energy flows? Explain.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use investigation data to describe where energy transfers and matter changes occur in the system. (SEP: 4.5; CCC: 5.2)
- Students tie rearrangements of atoms, or the breaking of bonds, to energy stored in the field. (DCI: PS1.B.1)
- Students tie their new data back to energy flows in the cylinder system. (SEP: 4.5; CCC: 5.2)

What to do: Provide feedback on students' responses. If students do not tie back to investigation data, ask, *What did we see in class that would make us think this?* Encourage students to refer back to their energy transfer models and collision models if they do not clearly articulate the energy inputs and changes (i.e., kinetic energy decreases as particles get farther apart), or do not tie them to particle behavior. Students can use this feedback as they try to combine thinking about bonds breaking and bonds forming on day 2 of Lesson 5.

Question 3 is intended to help navigate into the next lesson by problematizing that we still cannot account for the significant energy transfer to the engine provided by carbon-based fuels. Question 4 is intended for students to self-assess and provide feedback on ideas that are still confusing to them.

Building toward 4.A.2 Evaluate the impact of new data on the model of the cylinder system to conclude that changes in matter and energy occur when a bond is broken. (SEP: 4.5; DCI: PS1.B.1; CCC: 5.2)

LESSON 5: How and why is energy released when we burn carbon-based fuels?

PREVIOUS LESSON

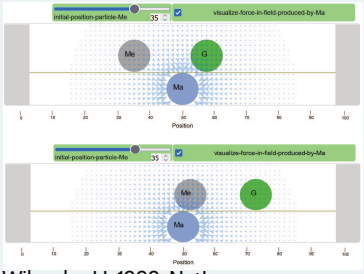
We investigated why an energy input was needed to start the combustion reactions of gasoline and diesel fuel. We figured out that matter is conserved. We used magnet marbles to develop ideas about the energy and forces occurring during the reaction. We used a computer model to quantify the energy and forces in the reaction. We built understanding about what is happening to the reactants during combustion reactions.

THIS LESSON

INVESTIGATION

2 days





Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

We investigate bond formation using the magnet marbles and a simulation similar to the one from the prior lesson. We use the magnet marbles and simulation to observe the forces involved and energy changes that occur when a bond forms, and incorporate new learning into an updated class consensus model. We read about two different fuels and trace the conservation of energy back to the sun for each fuel. We complete an Electronic Exit Ticket to assess our understanding of changes in matter and energy when bonds form.

NEXT LESSON

We will observe breaking and forming bonds with the magnet marble system. We will use a computer model to collect data on the kinetic energy and the energy stored in fields as this happens. We will use the data to argue for where energy is being transferred and how energy is conserved.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1



WHAT STUDENTS WILL DO

5.A Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2)

5.B Evaluate claims about fuels and trace the conservation of energy from the fuel's formation to its use while considering the impacts fuels and their use have had on human populations. (SEP: 7.2; DCI: ESS3.A.1, ESS3.B.1; CCC: 5.3)

WHAT STUDENTS WILL FIGURE OUT

- As attracted particles move closer together, there is a decrease in the energy stored in the field and an increase in kinetic energy.
- Forming a chemical bond results in an increase in particle-level kinetic energy.
- Energy in all fuels can be traced back to the sun. These resources are important because they allow for the development of society and affect where and how people live.
- There are arguments for and against fossil fuels and biofuels.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Have students consider where CO_2 comes from in combustion.	A-C	1 magnet marble and ruler system, 1 metal marble, 1 glass marble, 1 ruler, 3 box stands
2	5 min	✓	**INVESTIGATE BOND FORMATION** Complete the Marble Interactions Demonstration. Lead a whole-class discussion about the demonstration results.	D-E	Marble Interactions Demonstration
3	10 min	✓	**DEVELOP PREDICTIVE MODELS** Lead a whole-class discussion about forces in the marble system. Have students individually develop and then share predictive models with a partner.	F-H	*Predicting Energy Changes*, M-E-F poster
4	10 min	✓	**TEST PREDICTIONS WITH A SIMULATION** Have students work with a partner to use a simulation to test their predictions and determine the effect of distance on kinetic energy. Lead a whole-class discussion to identify the M-E-F relationships in the system.	I-J	*Predicting Energy Changes*, internet-connected device, https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR.html, https://youtu.be/GE4wO-eHM5w (optional), M-E-F poster
5	10 min	✓	**REFLECT ON SIMULATION AND REVISE MODELS** Lead a whole-class discussion to revise the "Bonds Breaking" model from Lesson 4. Have students individually complete *Predicting Energy Changes*.	K-L	*Predicting Energy Changes*, *Bonds Breaking/Forming*, chart paper, chart paper markers, M-E-F poster
6	5 min	✓	**ASSESS A CLAIM** Have students write an individual explanation for how a particular fuel releases energy when it combusts.	M	*Predicting Energy Changes*
					End of day 1
7	4 min		**NAVIGATE** Have students share their individual explanations with a partner for feedback.	N	*Predicting Energy Changes*
8	10 min		**RETURN TO OUR INITIAL CONSENSUS MODEL** Work with the class to revise our initial consensus model for how a fuel releases energy to make a vehicle move.	O	chart paper, chart paper markers, initial consensus model from Lesson 1, Fuel Data Cards (optional)
9	10 min		**READ ARGUMENTS ABOUT FOSSIL FUELS AND BIOFUELS** Have students complete a reading about the energy sources for fossil fuels and biofuels.	P-Q	*Comparing Fuels*, Fuel Data Cards (optional)
10	11 min	✓	**DEBRIEF ARGUMENTS ABOUT FUELS** Lead a class discussion about the advantages and disadvantages of fossil fuels and biofuels, then have students update their Progress Trackers.	R-S	*Comparing Fuels*
11	10 min	✓	**COMPLETE AN ELECTRONIC EXIT TICKET** Have students complete the Electronic Exit Ticket.	T	Electronic Exit Ticket link, internet-connected device
					End of day 2

Lesson 5 • Materials List

	per student	per group	per class
Marble Interactions Demonstration materials	• science notebook		• 1 stronger magnet marble and ruler system • 1 metal marble • 1 glass marble • 1 ruler • 3 box stands • clear tape
Lesson materials	• *Predicting Energy Changes* • *Comparing Fuels* • science notebook • Electronic Exit Ticket link • internet-connected device	• internet-connected device • https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR.html	• 1 magnet marble and ruler system • 1 metal marble • 1 glass marble • 1 ruler • 3 box stands • M-E-F poster • https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR.html • https://youtu.be/GE4wO-eHM5w (optional) • *Bonds Breaking/Forming* • chart paper • chart paper markers • initial consensus model from Lesson 1 • Fuel Data Cards (optional)

Materials preparation (30 minutes)

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

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

Three-hole-punch all handouts so they can be added to students' notebooks. Have the "Mapping to the Cylinder System" poster from Lesson 4 visible during this lesson. Have the "Bonds Breaking" model from the end of Lesson 4 ready to display.

Create Electronic Exit Ticket surveys for this lesson using the directions found on *Electronic Exit Tickets*.

Test both possible versions of the simulation. As in Lesson 4, an expanded version provides particle-level information about the energy.

- Default: https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR.html
- Expanded: https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR+expanded.html

Day 1: Marble Interactions Demonstration

- **Group size:** Whole class
- **Setup:** Prepare materials using *Building Marble Equipment*. Gather materials for the demonstration.
- **Notes during the lab:** Ensure that you do not lose any of the marbles, as they can be a falling hazard if left on the floor. It can be helpful to use a tray for catching the marbles.
- **Safety:** Ensure that students do not attempt to open the magnet marbles. Students could pinch their fingers or experience health emergencies if the magnets are swallowed.
- **Disposal:** Do not dispose of any materials.
- **Storage:** Store all materials in a cabinet for future use.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.B.1 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.~~
- **PS3.C.1 Relationship Between Energy and Forces:** When two objects interacting through a field change relative position, the energy stored in the field is changed.
- **ESS3.A.1 Natural Resources:** Resource availability has guided the development of human society.
- **ESS3.B.1 Natural Hazards:** ~~Natural hazards and other~~ geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations.

Crossout explanations: Students are not investigating reaction rates in this unit, as this was done in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. They will not equate the overall energy released or absorbed with total changes in bond energy until Lesson 7 of this unit. Students consider how the formation of fossil fuels over millions of years helped to alter human society as they compare fossil fuels to biofuels, but they do not consider other geologic processes in this unit. Natural hazards' impacts on society were considered in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

Students watch a demonstration of bond formation using the magnet marble physical model first introduced in Lesson 4 (DCI: PS1.B.1). They use their observations to *develop predictive models* of the *energy changes during bond formation* based on what they figured out in that lesson (SEP: 2.4). Students test their ideas using a simulation, which helps students visualize the *force interactions between the different atoms* (DCI: PS3.C.1). The class uses this information to *revise* the "As opposite charges move toward each other" portion of the *model* developed in *Electrostatics Unit* (SEP: 2.4). Students *apply this revised model* to e*valuate their predictive models* and identify *energy transfers, force interactions, and matter changes as bonds form* (SEP: 2.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2).

Students have an opportunity to construct an explanation and receive feedback on it before updating their consensus model (SEP: 6.4, 2.4). They also have an opportunity to engage with relatively brief *arguments* about fossil fuels and biofuels (SEP: 7.2). This will allow for students to engage with increasingly complex arguments throughout the unit, leading toward developing their own in Lesson Sets 2 and 3. This reading also provides space for students to trace energy in carbon-based fuels back to the sun and consider how energy resources have and will continue to affect development and human populations (DCI: ESS3.A.1, ESS3.B.1; CCC: 5.3).

Finally, students complete an Electronic Exit Ticket that prompts them to consider *why some models they used or developed* in the class were *better to use* as they work toward answering the lesson question (SEP: 2.4). This supports students' thinking around *merits and limitations of the models* they *used and developed* during the lesson.

Where We Are NOT Going

Students will record quantitative information about energy transfers when a bond forms. At this point, do not have them consider net bond energy released from the combustion reactions.

The ideas of net bond energy changes as a result of reactions, and defining *exothermic reactions*, are developed over the course of Lessons 3–7. In Lessons 4 and 5, students focused on energy transfers and changes during bond breaking OR bond formation. In Lesson 6, they combine these two pieces. In Lesson 7, students compare the bond strengths of atoms in both product and reactant molecules using electronegativities and magnet marbles. They qualitatively identify differences in energy inputs and outputs as a result of breaking and forming bonds. They also quantify these differences and develop definitions of *exothermic* and *endothermic reactions*.

We are not going to refer to energy stored in fields as "potential energy" in this lesson. "Potential energy" is used only parenthetically or as a shorthand when citing examples of energy stored in gravitational, electric, and magnetic fields in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Academies Press, 2012). While you could introduce it as a shorthand for energy stored in fields, using "potential energy" in the classroom may lead to misconceptions, such as:

- associating potential energy with an object rather than a system of objects that produces a field;
- thinking of it as a form of energy, rather than focusing on the field as an important part of the system that can store and transfer energy.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

MATERIALS: 1 magnet marble and ruler system, 1 metal marble, 1 glass marble, 1 ruler, 3 box stands

ADDITIONAL GUIDANCE

It will be helpful to have an investigation setup displayed so it is visible to all students. You will use this setup in the next lesson step. If students ask, invite them to collect the rulers, marbles, and boxes to use while they discuss the prompts on the slide.

Recall what we wondered last class. Display **slide A**. Say, *At the end of last class you were asked to consider why we still use carbon-based fuels even though we know they release CO_2. Let's talk about why that is.*

Suggested prompt	Sample student response
What did we figure out last class?	We have to put energy in to break a bond. If we don't put enough energy in, the bond doesn't break, but the marble comes back.
Why do we continue to use carbon-based fuels, even though they release CO_2?	We get a lot of energy out of the fuels. We have a lot of them and our cars are designed for them.

Point out that these two ideas seem to be at odds with each other: burning fuels releases energy, but energy input is required to break bonds. Suggest that we figure out where the energy from fuels is coming from.

Consider how we could investigate this question. Display **slide B** and show students the materials from the last class. Have students turn and talk with a partner about the prompt on the slide for one minute. Ask for a few volunteers to share what they discussed.

Suggested prompt	Sample student response
How could we use our investigation materials from last class to figure out how energy gets released when carbon-based fuels burn?	We can try to make a bond instead of break a bond. We need to "bond" the magnet marbles instead of separating them.
What two marbles do we need to show a bond forming?	The two magnet marbles, or a magnet marble and a metal marble.
Where or how would we place them on the ruler?	We should start with marbles apart instead of together.
How would we represent energy and energy transfer?	The glass marble can represent energy here too.

If students do not suggest using the glass marble, or say it is not needed, refer to the work the class did in the previous lesson to map the marbles to the cylinder system, and again ask students how they represented energy in the previous investigation. ✱ If students are still unsure about using the glass marble to represent energy, that is okay. During the investigations, students will likely realize that the glass marble is still needed to represent energy or particle collisions, just as it did last class.

✱ ATTENDING TO EQUITY

Students have the opportunity to begin modeling bond formation with the marbles of their choice, even though they may realize later that they need the glass marble to show energy coming out of the system. This type of subtle move gives students *epistemic agency*, or the decision-making power to move their knowledge forward. This is good for learning because students are figuring out how to represent a bond, rather than just learning about it in a rote way.

Clarify the boundaries of the system. Display **slide C**. Ask, *Where is the energy in the system?* If students do not say that energy is in the field, prompt them to recall what they observed when breaking bonds last class.

Say, *When we say energy or matter goes in or out, we mean in or out of the system; but what are the boundaries of the system we are talking about?* Look for students to say

- atoms (or marbles on the ruler),
- the bonded atoms (or marbles on the ruler), or
- the bond, atoms, and field between them.

Emphasize that the important part is that the class is in agreement on how to define the system, so that when someone says energy is going "in" or "out," everyone knows what that means. Then agree as a class on how exactly to represent bond formation with the ruler and marbles. You may want to record this on the board.

2 · INVESTIGATE BOND FORMATION

5 min

MATERIALS: Marble Interactions Demonstration

Test ideas with marbles. Display **slide D**. Say, *Let's test your ideas with the investigation materials from our last lesson.* Set up the ruler and marbles as students suggested. If the metal marble does not start rolling, ask students what to do. They should suggest moving the metal marble closer to the magnet marble.

ADDITIONAL GUIDANCE

If a document camera is available it could be helpful to use while demonstrating with the ruler and marbles, as it will allow students farther away to see the demonstration better. You can also show students a normal-speed and a slow-motion video using https://www.youtube.com/watch?v=c-kVUpcifyg and https://www.youtube.com/watch?v=kVpiyFvWAhQ.

ALTERNATE ACTIVITY

If time permits or if students seemed to benefit from the hands-on investigations in Lesson 4, have students investigate with the materials instead of doing this step as a demonstration. As students investigate, circulate to make sure that they are trying to form a bond at different distances from the magnet marble, and that they are using the glass marble as well.

If you leave this opportunity as a demonstration, consider having a student come to the front to handle the marble and ruler setup.

Determine where energy transfers are occurring.✱ Discuss the prompts on **slide E** as a class.

Suggested prompt	Sample student response
What evidence did you observe that suggests there is a change in energy in the system when a bond forms?	The metal marble starts moving on its own; we don't push it. The metal marble hits the glass marble and the glass marble rolls away. There is a cracking sound when the marbles collide.

✱ SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

This is the first use of this SEP in the unit. Provide students plenty of support as they use multiple collision models to support explanations related to energy transfers during bond formation. The evidence will become more complex in the next lesson as students use different simulations.

Suggested prompt	Sample student response
Is this a transfer of energy into or out of the system?	The energy goes from the field to the metal marble to the glass, so that is an output. The sound and the movement of the glass marble show an output of energy.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students identify evidence of energy transfers by sharing observations about the changes in kinetic energy. (DCI: PS1.B.1; CCC: 5.2)

What to do: Students may not think their observations are enough evidence to definitively say there are energy transfers occurring in the system. Run the Marble Interactions Demonstration again, this time placing the metal marble closer to the magnet marble, and tell students to focus on the change in kinetic energy of the glass marble. At this point it is okay if students are unsure whether there is an energy input or output in the system. This will be clarified when students use the simulation later in the lesson.

Building toward 5.A.1 Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2)

3 · DEVELOP PREDICTIVE MODELS

10 min

MATERIALS: *Predicting Energy Changes*, M-E-F poster

Identify where the forces and energy are in the marble system. Display **slide F** and distribute *Predicting Energy Changes*. Say, *Let's take a minute to think about where the forces and energy are in the marble system. On Predicting Energy Changes, there are two different collision models you will complete where you can identify the changes in matter, energy, and forces. We have already talked a bit about energy and matter. Let's consider where the forces are in the marble system.*

Suggested prompt	Sample student response
What makes the metal marble start moving?	The magnetic force is pulling on the marble.
What can you infer about the strength of the forces?	It seems to be pulling more weakly at a distance. The farther away the metal marble is from the magnet marble, the weaker the forces.

ADDITIONAL GUIDANCE

At this point, do not push students to think about how these weaker forces add up as the metal marble moves a longer distance, resulting in a larger energy transfer to the glass marble. Students will notice this as they use a simulation later in the lesson.

Focus on bond formation. Display **slide G**. Say, *Let's model when the bond is formed between the magnet and metal marbles in Model 1 and Model 2 on the handout.* Give students about six minutes to develop their Models 1 and 2 on *Predicting Energy Changes*. ✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

Have the M-E-F poster available for students to view as they develop their predictive models. This will support students as they tease apart areas where *forces and energy transfer* overlap at the moment of the particle (glass marble and metal marble) collision. (CCC: 5.2)

Display **slide H**. Have students meet with a partner to share their collision models and identify areas of agreement and disagreement. Giving students time to consider these areas of disagreement will highlight the uncertainty that is present, which will help motivate the need for the simulation. After two to three minutes, use the following prompts to lead a discussion.

Suggested prompt	Sample student response
Where did your models agree?	We both showed the glass marble moving farther when the metal marble started farther away. We showed the glass marble not moving as far when the metal marble started closer.
Where did your models disagree?	We showed different amounts of kinetic energy.
Do you think the distance matters?	Maybe. I think so because the snap sound is bigger when the metal marble is farther away because it zooms in faster.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students develop and use collision models and identify changes in matter and energy and energy transfers. (SEP: 2.4; CCC: 5.2)
- Students identify the relationship between objects moving through a field and changes in energy. (DCI: PS3.C.1)
- Students identify areas of agreement and disagreement in their models. (SEP: 2.4)

What to do: Push students to clarify their thinking, especially where they disagree. Remind students of how the class has agreed to show kinetic energy previously, with longer or larger arrows or lines to show greater energy. If students are not sure whether a bond forming from different distances results in a different energy output, encourage them to make their best prediction based on what they have observed so far. As students share their models, prompt them to explain their visual work, especially as it connects to the relationships between matter, energy, and forces that they are trying to predict.

Building toward 5.A.2 Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2)

Summarize and motivate the use of a simulation. Say, *I heard some areas of disagreement in our models; let's take a moment to share those.* Ask for volunteers to share where there is uncertainty in their models. Listen for responses related to the relationship between distance and the amount of energy released, or simply the unknown amount of energy that is released. Then ask what might help clear up some of this uncertainty. Listen for students to say they need a way to measure or quantify the energy and distance. Students may suggest using the simulation from last class or something similar.

Say, *I have a simulation that is similar to the one we used last class that can help us investigate bonds forming in the same way we investigated bonds breaking.* Elicit ideas about what the simulation might help us figure out that the physical model could not.

4 · TEST PREDICTIONS WITH A SIMULATION

10 min

MATERIALS: *Predicting Energy Changes*, internet-connected device, https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR.html, https://youtu.be/GE4wO-eHM5w (optional), M-E-F poster

Introduce the simulation. If desired, display **slide I** and play the introduction video: https://youtu.be/GE4wO-eHM5w. After students have viewed the introduction video ask if they have any clarifying questions. Ask, *What will this simulation help us to test?* Listen for students to say that they will test their predictions from their collision models, or that they will investigate the relationship between distance and forces or energy transfers.

ADDITIONAL GUIDANCE

The video introducing the simulation may not be necessary, as it is similar to the simulation students used in Lesson 4 to investigate bonds breaking. You can skip it if you think students are familiar enough with the simulation by the end of Lesson 4, or choose to show the video if students struggle with using the simulation.

Test predictions with the simulation. Display **slide J**. Open https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR.html. Have students meet with a partner and open the simulation. Run the simulation and then talk through the types of data students could collect. Direct them to the data table on *Predicting Energy Changes*, where students should record data as they conduct their investigations with the simulation. Remind students that we wanted to use the simulation to test predictions about matter, energy, and force changes as bonds form as well as determine whether distance between atoms (the marbles) matters. ✱ Give partners five minutes to collect data using the simulation.

See *Predicting Energy Changes Key* for a sample student data table.

Discuss relationships between matter, energy, and forces. Have the M-E-F poster visible. Use the prompts on the poster and below to lead a discussion about the investigation data.

Suggested prompts	Sample student responses	Follow-up questions
What changes did we observe in the matter?	Particle Me moved into the system and Particle G moved out of the system.	*What was the cause of those changes?*
Where did the forces acting on the matter come from?	The field coming from Particle Ma.	*What happened to the amount of force applied through the field as the distance changed?*
How did this affect the amount of energy transferred from the metal marble to the glass marble?	When there were more forces applied, so greater distance, there was more energy transferred. This means that the glass marble had more kinetic energy.	*Based on what is happening to the energy changes in the system, is energy being released or absorbed?*

Students should now agree that energy is released OUT of the system, and they can see the increase in kinetic energy when the bond forms between the magnet marble and metal marble. Students may also mention that because the glass marble leaves the system, that is also indicating an energy transfer out of the system. Ask students how we could represent this energy transfer so it is easier to trace; listen for the suggestion of energy transfer models. If students do not bring this up, ask them to think about how we represented energy transfer in the previous lesson.

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Students are not formally being asked to develop an investigation plan, but may *benefit from some time to verbally talk through this with their partner, you, or the whole class*. As partners are working with the simulation, ask questions to ensure that students are using the simulation in a way that will *produce data to either support or refute their predictive models*. Examine the data tables students develop to ensure that the way they are organized will support students in using the data to evaluate their predictive models. (SEP: 3.1)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use models and identify changes in matter and energy and energy transfers. (SEP: 2.4; CCC: 5.2)
- Students identify evidence of energy transfers by sharing observations about the changes in kinetic energy. (DCI: PS1.B.1; CCC: 5.2)
- Students identify the relationship between objects moving through a field and changes in energy. (DCI: PS3.C.1)

What to do: If students struggle to discuss matter changes, either run the simulation or repeat the Marble Interactions Demonstration and point out the changes in the matter/marbles. If students struggle to describe the role of forces and where they are located, see the following alternate activity guidance. If students struggle to make connections between forces and energy, run the simulation and have students focus on the "Energy Stored in the Field" and "Total Kinetic Energy of all Particles" graphs. Also encourage students to look at the "Energy Stored in the Field" values as the starting distance of particle *Me* is changed.

Building toward 5.A.3 Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2)

ALTERNATE ACTIVITY

If your students are struggling to describe the role of forces, use https://lab.concord.org/embeddable.html#interactives/interactions/electricPE3.json. This simulation provides better visualization of the different charges and their associated fields to help support force thinking. It also shows that energy stored in the field (potential energy) is affected by the distance between the two charges.

5 · REFLECT ON SIMULATION AND REVISE MODELS

10 min

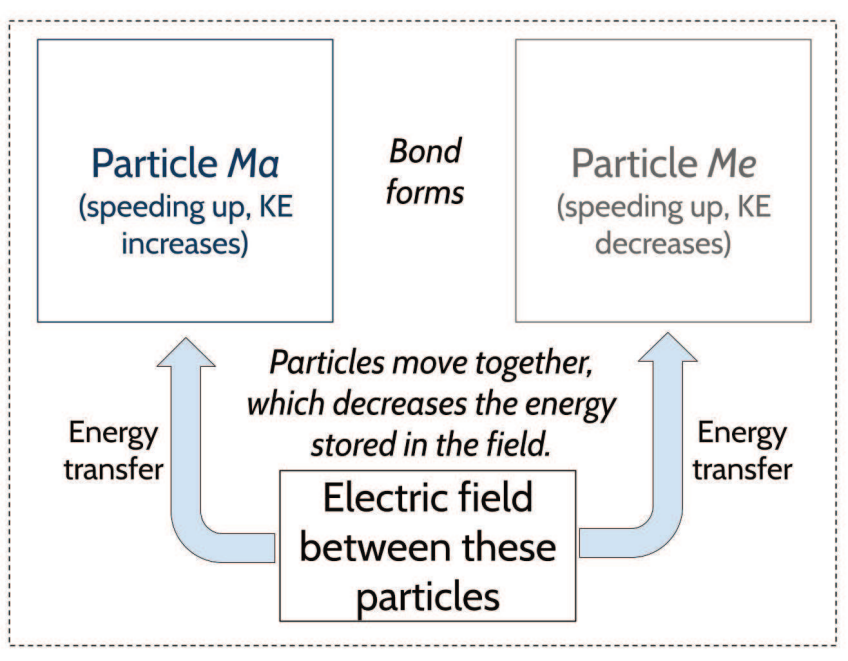
MATERIALS: *Predicting Energy Changes*, *Bonds Breaking/Forming*, chart paper, chart paper markers, M-E-F poster

Revise the "Bonds Breaking" model from Lesson 4. Display **slide K** and say, *Last class we modeled the energy transfers involved in breaking bonds*. Ask students to think about how to revise this model to explain why energy is released when bonds form. See *Bonds Breaking/Forming* for an example of this prior model.

Suggested prompt	Sample student response
Where does energy go when a bond breaks?	Into the field.
Where does the energy go when a bond forms?	Out of the field. Into the particles.
How can we revise this model to explain energy transfers during bond formation?	The arrows should show energy transferring from the field to the particles. The particles should speed up instead of slow down.

Tell students to help you revise the model to reflect a bond forming rather than breaking. Draw students' ideas on a piece of chart paper. Start by drawing a rectangle in the center labeled "Electric field between these particles," with a box labeled "Particle *Ma*" above and to the left and a box labeled "Particle *Me*" above and to the right, just as they are shown on **slide K.**

Suggested prompt	Sample student response
What did the arrows in the simulation indicate happens as the particles move toward each other?	The force of attraction gets stronger. Energy is transferred to the atoms from the field. On the chart paper, draw arrows pointing from the **Electric field between these particles** box to the **Particle Ma** and **Particle Me** boxes, and label these arrows "Energy transfer."
What happens to the energy stored in the field?	It decreases. Add the text, "Particles move together, which decreases energy stored in the field" to the **Electric field between these particles** box.
How does the energy transfer from the field affect each particle?	It causes them to speed up. Add this text to each **Particle** box: "Speeding up (KE increases)".



Ask, *So how does this revised model help us explain why energy is released when a bond forms?* Look for students to suggest that energy is transferred from the field to the two particles as they form a bond.

Identify where the forces and energy are in the marble system. Display **slide L**. Say, *Now I want you to reflect on your predictive models and whether the simulation supported or refuted your predictions. Then I want you to consider the merits and limitations of the different models we have used today.* Give students the remaining time of this lesson step to complete the Model Reflection on *Predicting Energy Changes*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify evidence of energy transfers by sharing observations about the changes in kinetic energy. (DCI: PS1.B.1; CCC: 5.2)
- Students develop and use models and identify changes in matter and energy and energy transfers. (SEP: 2.4; CCC: 5.2)
- Students identify both the merits and limitations of the simulation and the magnet marble and ruler system. (SEP: 2.4)
- Students identify the relationship between objects moving through a field and changes in energy. (DCI: PS3.C.1)

What to do: *Predicting Energy Changes Key* provides expected student responses. If students do not include all changes in matter or energy or forces in their models, encourage them to think back to the discussion about the relationships between matter, energy, and forces (**slide J**). If students struggle to come up with merits and limitations of the different models they have used, ask them which model allowed them to better track energy changes, or which model allowed them to better observe various conditions of bond formation.

Building toward 5.A.4 Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2)

6 · ASSESS A CLAIM

5 min

MATERIALS: *Predicting Energy Changes*

Assess a claim. Display **slide M.** Tell students, *Now that you have used several models to observe and make sense of energy transfer during bond formation, take a moment to use your models to assess a claim.* Direct students to the last prompt on *Predicting Energy Changes*, Tell them that if they need to, they can use models as part of their written explanation. Also tell students that this is a first draft and that they will have more time to think about it and contribute ideas to a class consensus model next class, so they do not need to worry if they feel they do not have a complete answer at this point in time.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students cite their models in their assessment of the claim. (SEP: 6.4)
- Students confirm the claim that energy flows from fields to particles when a bond forms. (DCI: PS1.B.1, CCC: 5.2)

What to do: Collect *Predicting Energy Changes* as a formative assessment, but record feedback separately from the document so that students are not influenced by your thinking when they provide peer feedback in the next class. Encourage students to refer back to their data tables from the simulation, as well as their responses to the reflection questions on *Predicting Energy Changes*. If students are unsure how to start, it may help them to talk through their responses first. Ask students to tell you whether the claim is true or not and then tell you how they know.

Building toward 5.A.5 Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2)

End of day 1

7 · NAVIGATE

4 min

MATERIALS: *Predicting Energy Changes*

Navigate. Start class by having students share their explanations from last class with a partner. Display **slide N**. Tell students that they will use their explanations and feedback to help update our initial consensus model, and to be prepared to share the ideas they see and hear during conversations with their partners in the upcoming class discussion. Tell students to spend about a minute each sharing their explanation with their partner, and then the next two minutes giving each other feedback.

ALTERNATE ACTIVITY

To support peer assessment, you may wish to provide sentence starters--for example, "I like how you _____. Your explanation would be stronger if you _____." Students will have to give and receive feedback in a structured way in Lesson 14, as well as in less structured moments throughout the unit. You may wish to have students reflect on how they gave and received feedback in this activity. A standard template for self-assessment when giving or receiving feedback, along with routines and more tools for peer assessment, may be found in the *OpenSciEd Teacher Handbook: High School Science*.

8 · RETURN TO OUR INITIAL CONSENSUS MODEL

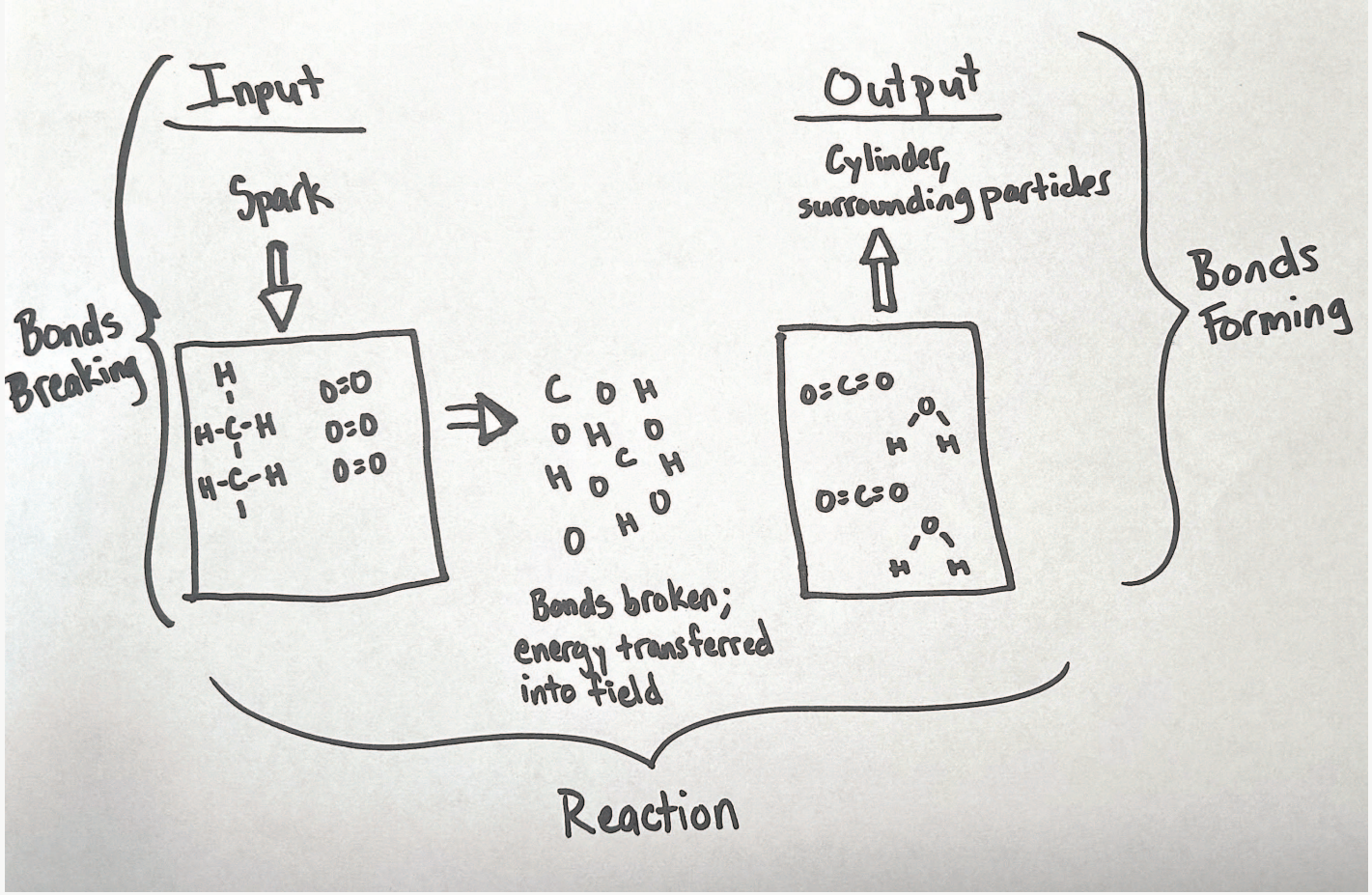
10 min

MATERIALS: chart paper, chart paper markers, initial consensus model from Lesson 1, Fuel Data Cards (optional)

Revise the initial consensus model. Display **slide O**. Tell students, *We have figured out a lot about what happens when fuels combust and how energy changes.* Suggest taking a moment to update our initial consensus model from Lesson 1. Have the model visible in the room for students to reference. Ask students what could be added to the class model. Listen for:

- bonds breaking and forming
- the components of a combustion reaction: fuel, oxygen, water vapor, and carbon dioxide
- energy transferring into particles to break bonds
- energy transferring from particles to the field when bonds break
- energy transferring from the field to particles when bonds form

As students suggest these ideas, ask for specifics on how to add them to the model.



ADDITIONAL GUIDANCE

If you have space on the initial consensus model from Lesson 1, you can make these changes directly on that model. If not, use a new piece of chart paper, but keep the initial consensus model visible for students' reference.

Reflect on the model. Ask, *What does our model tell us about carbon-based fuels? What does it leave out?* Listen for the idea that it tells us quite a bit about how these fuels work, but it does not tell us whether or not we should use them. If students do not bring up this idea, asking them what we ultimately want to figure out in the unit may help them remember that we care about which fuels we should use. Highlight to students that the model shows us science (how things work), but the question of what we should do is more based in engineering.

Elicit students' ideas about the different types of carbon-based fuels. If necessary, show several Fuel Data Cards and remind students that some are made from substances like oil, natural gas, and coal, while others are made from living things.

9 · READ ARGUMENTS ABOUT FOSSIL FUELS AND BIOFUELS

10 min

MATERIALS: *Comparing Fuels*, Fuel Data Cards (optional)

Consider where fuels' energy comes from. Display **slide P** and say to students, *We know that we get a lot of energy from fossil fuels, but we also know they release a lot of carbon dioxide. But are fossil fuels our only source of carbon-based fuels?* Look for students to suggest biofuels. If needed, take a moment to return to the Fuel Data Cards so that students can remind themselves of the other fuel options. Once biofuels are brought up as an option, push students to consider how they may be similar to or different from fossil fuels. Accept all ideas here. For similarities, students may suggest their composition, amount of energy released, and uses. For differences, students may suggest how the fuels are formed, their environmental impacts, and their availability.

Read about two fuel sources. Display **slide Q** and distribute *Comparing Fuels*. Give students eight minutes to read with a partner and complete the questions on the handout.

10 · DEBRIEF ARGUMENTS ABOUT FUELS

11 min

MATERIALS: *Comparing Fuels*, science notebook

Discuss the reading as a class. Display **slide R** and discuss the prompts on the slide.

Suggested prompt	Sample student response
What do these fuels have in common?	They both come from living things. They both release and absorb carbon dioxide. Both fuels need inputs like water and other resources to be produced.
Why might we want to use one fuel over the other?	Human population is growing and biofuels use land that we need to grow crops. We already have the infrastructure for fossil fuels so it's easy to keep using them. Biofuels are carbon neutral so don't contribute to climate change or pollute as much. Biofuels aren't as hazardous or damaging to the immediate environment to obtain, especially if made from waste or something like algae. We cannot run out of biofuels like we will run out of fossil fuels.

Suggested prompt	Sample student response
What criteria and constraints must we consider when thinking about how to improve our fuel or transportation systems?	We need to consider the resources that go into making the fuel and the availability of the fuel. We need to consider energy released. We need to consider carbon dioxide and pollution.
Why is it so important to think about where the energy in fuels comes from?	We need to know whether the process releases additional carbon dioxide. Energy is conserved, so it has to come from somewhere.

ALTERNATE ACTIVITY

Extension opportunity: Because of impurities and incomplete combustion, carbon-based fuels typically release pollutants when burned. This causes health impacts which are concentrated in places where carbon-based fuels, particularly fossil fuels, are burned. Often, the greatest amounts of fossil fuel burning occur with heavy equipment and industrial activities that are disproportionately found in historically lower-income or minoritized communities. You may wish to have students research air pollution in their own community and region, starting with a site like AirNow.gov. Have students follow their questions, which may include:

- Where is air pollution the highest?
- What possible sources could explain these pollutants?
- Who is most affected and why?
- What has been done to address this issue? What can we do or advocate for?

Say, *We have a little more information about different fuels. Let's make sure we capture the implications of those new ideas in our Progress Trackers.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students connect both fuels back to the sun as the original energy source. (CCC: 5.3)
- Students discuss the claims in the article as to impacts of the two fuels on human populations while considering the continued use of both fuels. (SEP: 7.2; DCI: ESS3.A.1, ESS3.B.1)

What to do: Push students to consider how the production and use of each fuel is related to continued human population growth. Help students break down the points of the reading to connect energy released and carbon dioxide emissions to human population and other resource needs.

Building toward 5.B.1 Evaluate claims about fuels and trace the conservation of energy from the fuel's formation to its use while considering the impacts fuels and their use have had on human populations. (SEP: 7.2; DCI: ESS3.A.1, ESS3.B.1; CCC: 5.3)

Update Progress Trackers. Display **slide S** and give students a few minutes to update their Progress Trackers. A sample entry can be found in *Progress Tracker Key* and below. Ensure that students add new criteria and constraints at the top of the tracker as well.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	**Engineering implications** Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
When bonds form, energy transfers from the field to particles. The energy in fossil fuels and in biofuels comes from the sun. There are advantages and disadvantages to both fossil fuels and biofuels. We figured this out from modeling and engaging with arguments that traced energy.	*Fossil fuels have higher energy released and are already compatible with most vehicle types. There is already infrastructure for the widespread use of fossil fuels, but they produce more carbon dioxide emissions as well as other forms of pollution. Biofuels have lower emissions and pollution, but also lower energy released. They are also not as available as fossil fuels and require land to grow. They could become a better option in the future because of a decreased need for cropland and associated carbon dioxide emissions to grow them.*	Avoid: *Both fuels where possible. Fossil fuels especially because they cause more pollution and carbon emissions. But biofuels use land that could otherwise be used to grow crops, so we don't want to use too much of those either.* Shift: *To biofuels where possible, as a lower carbon alternative to fossil fuels. Or shift to different forms of transportation that don't require either.* Improve: *Use less land or land more responsibly for growing feedstocks, and/or improve the feedstocks used for biofuels. Use more energy efficient transportation options.*

Connect back to the cylinder system. Continue to display **slide S**. Point out that we modeled this system before thinking about energy at a more global scale. Ask, *Whether there are biofuels or fossil fuels in the tank, how confident are we in our model of what is happening in the reaction? Can we fully explain it?* Listen for the idea that since we have not put breaking and forming bonds together or tried to apply the model to very many real fuels, we have more work to do.

11 · COMPLETE AN ELECTRONIC EXIT TICKET

10 min

MATERIALS: science notebook, Electronic Exit Ticket link, internet-connected device

Complete an Electronic Exit Ticket. Display **slide T**. Have students complete the exit ticket using the link you created for your class. Encourage students to use their notes and models to help them answer the questions on the Electronic Exit Ticket.

ADDITIONAL GUIDANCE

See the instructions on *Electronic Exit Tickets* for how to create Electronic Exit Tickets for your class, using https://docs.google.com/forms/d/1WLFipq9FUZx8d4wat28iDdBPdgSK-0SV0s2_OQV3UDI/copy. Students will complete a second Electronic Exit Ticket in Lesson 11.

ASSESSMENT OPPORTUNITY	**What to look/listen for in the moment:** See *L5 Electronic Exit Ticket* for guidance. **What to do:** See *L5 Electronic Exit Ticket* for guidance. **Building toward 5.A.6** Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2)

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students use text to compare fuels, as well as the advantages and disadvantages of different fuels.

LESSON 6: How does the amount of energy we put into the reaction system compare to the energy we get out?

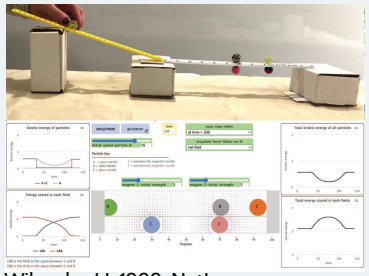
PREVIOUS LESSON

We investigated bond formation using the magnet marbles and a simulation similar to the one from Lesson 4. We figured out that bond formations result in an increase in kinetic energy. We updated our class consensus model and read about two different fuels. We completed an Electronic Exit Ticket to assess our understanding of these ideas.

THIS LESSON

INVESTIGATION

1 day



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

We observe breaking and forming bonds with the magnet marble system. This is tricky, so we use a computer model to carry out similar investigations. We collect data on the kinetic energy of the particles and the energy stored in fields as bonds break and form. We use the data to present and compare arguments for where energy is being transferred to/from and how energy is conserved in the entire process.

NEXT LESSON

We will use past knowledge to make sense of the different bond energies that are observed in different types of bonds. We will use these bond energies to create a visual and mathematical representation to figure out why some reactions lead to energy transferring out of the system. This knowledge will help us figure out why diesel has higher energy released values than gasoline. Then, we will look at a reaction where more energy is transferred in than out. We will end our class by revisiting the DQB.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

6.A Develop and revise models based on evidence and use these to present and compare an argument for an explanation of where energy is transferred to and from and why energy is conserved within a system when bonds break and form. (SEP: 2.3, 7.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.1, 5.2)

WHAT STUDENTS WILL FIGURE OUT

- The total energy (energy stored in electric fields and kinetic energy of particles) is conserved in a chemical reaction.
- In our simulation, net energy is transferred from the field if the bonds formed are stronger than the bonds broken.
- In our simulation, net energy is transferred to the field if the bonds broken are stronger than the bonds formed.
- A minimum amount of energy must be transferred to the field to break a bond and start the reaction. This is called the activation energy.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Have students stop and jot in their science notebooks about two prompts. Lead a brief discussion to decide how we could think about bonds both breaking and forming using familiar systems.	A	
2	7 min		**ORIENT TO THE TWO MAGNET MARBLE AND RULER SYSTEM** Show students the two magnet marble and ruler system and discuss how it compares to those used in previous lessons.	B-D	Two Magnet Marble System Demonstration
3	15 min		**INVESTIGATE BOND BREAKING AND FORMING WITH A SIMULATION** Show students a new simulation, help them recognize the need for another variable (bond strength), and have them investigate with a second simulation that includes the additional component.	E-H	*Breaking/Forming Bonds*, internet-connected device, https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR1.html, https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html, projector with sound
4	18 min		**DISCUSS AND MODEL ENERGY TRANSFERS** Lead a whole-class discussion about the simulation results. Have students work in pairs to complete *Modeling Energy Changes*.	I-L	*Modeling Energy Changes*, https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html, internet-connected device, projector with sound
5	2 min		**NAVIGATE** Lead a brief discussion to consider how we can use what we figured out to explain the energy we get from combusting fuels.	M	

End of day 1

Lesson 6 • Materials List

	per student	per group	per class
Two Magnet Marble System Demonstration materials			• 1 two magnet marble and ruler system • 2 glass marbles
Lesson materials	• science notebook • *Breaking/Forming Bonds* • internet-connected device • https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR1.html • https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html • *Modeling Energy Changes*		• internet-connected device • projector with sound • https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html

Materials preparation (45 minutes)

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

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

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

Have the "Mapping to the Cylinder System" poster from Lesson 4 visible during this lesson.

Test the simulations:
- Simulation 1: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR1.html
- Simulation 2: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html

The first simulation does not include bond strength, and students will figure out that it cannot give the expected results of energy being released. This will motivate the need for the second simulation. https://youtu.be/IY3jMhxMUSA provides an overview of all simulations in this lesson.

As in prior lessons, each simulation has an alternate version which provides particle-level data on energy:
- Simulation 1 expanded: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR1+expanded.html
- Simulation 2 expanded: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2+expanded.html

The magnet marble system is demonstrated in this lesson. Although students mainly rely on the simulation for sensemaking, you may find one or more of these videos useful to support students who strongly connected to the physical model:
- No bonds: https://www.youtube.com/watch?v=xVWJQ8hnLWk
- No bonds (slow motion): https://www.youtube.com/watch?v=bvfhsslYzYc
- Equal-strength bonds: https://www.youtube.com/watch?v=Wcv2KDKZaLc
- Equal-strength bonds (slow motion): https://www.youtube.com/watch?v=OEk_Se2Yh2w
- Weak bond breaking, strong bond forming: https://www.youtube.com/watch?v=_djO_YxM3XO
- Weak bond breaking, strong bond forming (slow motion): https://www.youtube.com/watch?v=ae1UvS1gO_U

Day 1: Two Magnet Marble System Demonstration
- **Group size:** Whole class

- **Setup:** Prepare materials using *Building Marble Equipment*.
- **Notes for during the lab:** Ensure that you do not lose any of the marbles, as these can be a falling hazard if left on the floor. It is recommended that you set up a box or tray for catching the marbles.
- **Safety:** Ensure that students do not attempt to open the magnet marbles. Students could pinch their fingers or experience health emergencies if the magnets are swallowed.
- **Disposal:** Do not dispose of any materials.
- **Storage:** Store all materials in a cabinet for future use.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.B.1 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.
- **PS3.C.1 Relationship Between Energy and Forces:** When two objects interacting through a field change relative position, the energy stored in the field is changed.

Crossout explanation: Students will name bond energies as such and quantify them in the next lesson. They have prior experiences with reaction rates from *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

In Lesson 4, students developed a model to represent the energy transfers between particles and electric fields and used it to explain why a minimum amount of energy input is required to break bonds of stable reactant molecules in combustion reactions. In Lesson 5, they extended that model to account for why kinetic energy of particles increases when bonds form as energy is transferred out of an electric field.

In this lesson, students put these two different parts of the chemical reaction process together. They begin to account for and *model the relationship* between the *kinetic energy of particles* in the system and the *energy stored in fields* as bonds of different strengths break and form (SEP: 2.3; CCC: 5.2). They connect energy transfers between particles and the system to bonds breaking and forming, resulting in a net transfer of energy into or out of the system (DCI: PS1.B.1). The energy versus time graphs that students analyze from the simulation are relatively complex, but build on the representation students used in the prior two lessons.

Students *argue* for *energy conservation* (SEP: 7.4; CCC: 5.1) and tie their thinking to energy stored in the field (DCI: PS3.C.1). This builds on the M-E-F perspective thinking and the related M-E-F triangle they foregrounded across prior lessons.

In this lesson, students will co-construct a definition for the following term, which they should add to their Personal Glossaries: *activation energy.* **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

While students will be analyzing quantitative data to describe relative changes in the amount of kinetic energy of the particles when a single bond breaks and forms, they are not calculating net bond energy released from the combustion reactions. Students will do that in the next lesson, and then develop a definition of *exothermic reactions* and *endothermic reactions*.

The graph of "total energy stored in both fields" in this lesson is quite similar to the potential energy graphs that are typically used to represent exothermic and endothermic reactions, with the subtle difference that, by focusing on the particle level, the graphs in this lesson show more variation in moments where there is a "wobble" from bond formation. In assessment tasks, students will primarily focus on the "total kinetic energy of all particles" graphs instead, as these graphs provide a more intuitive sense of how energy changes relate to temperature changes. Therefore, students primarily will be encouraged to attend to kinetic energy, except when considering energy conservation.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

3 min

MATERIALS: science notebook

Reflect on the reaction in a cylinder. Say, *At the end of last class, we were wondering about what really happens when bonds break and form in the cylinder system. Today we can test those ideas.* Display **slide A** and give students two minutes to write independently in their science notebooks. Then discuss students' ideas as a class.

Suggested prompt	Sample student response
What does that have to do with choosing fuels for the future?	Fuels release energy when bonds break and form. Carbon dioxide is a product of the reaction. We need to understand what is happening when we use a fuel to help us decide if it can be improved.
How could we show this using the marble models and computer models?	We could set up marbles to represent a bond breaking, and then a different set of marbles to represent a bond forming. We could basically put the two simulations or the two investigation setups from the last few classes together. We should think about the whole input-reaction-output process.
How could we use these systems to explore the energy changes that occur when bonds break and form?	We could carefully observe the speed or energy of the marbles when bonds break or form. We could have graphs that show us the changes in energy.

2 · ORIENT TO THE TWO MAGNET MARBLE AND RULER SYSTEM

7 min

MATERIALS: Two Magnet Marble System Demonstration

Orient to the system. Show students a two magnet marble and ruler system.

Display **slide B**. Point out the labels in the picture so that students can identify the magnet marbles, metal marble, and glass marbles.

Suggested prompt	Sample student response
Where is there already a bond in this system?	Between metal marble Me and magnet marble M1.
Where would a new bond form after that first bond is broken from the collision with glass marble G2?	Over magnet marble M2

Take predictions. Display **slide C**. Say, *Let's just let the first glass marble go. I will release glass marble* G1 *from the 5-cm mark on the track. What do you think will happen to glass marble* G2*? How does this compare to what we would expect to happen in a combustion reaction?* Accept all responses. Students may suggest:

- The metal marble will hit the second glass marble and it will shoot off.
- The metal marble/magnet marble bond will not break.
- In a combustion reaction, you get a lot of energy out. So, that would be all the marbles shooting off after the first bond breaks.

Test the system. Display **slide D.** Demonstrate a trial run of this condition from a release location at 5 cm. Then discuss the prompts.

Suggested prompts	Sample student responses	Follow-up questions
How did the results compare to our predictions?	It was kind of hard to tell because the bond didn't break. The bond did break and the second glass marble got hit.	*In an actual combustion reaction, how would the energy of the particles before the reaction compare to the energy of the particles afterward?*
How might a simulation give us clearer information about what is happening to the energy?	It would give us exact numbers. It would let us pause and see what is happening at different points in time.	*Could it let us compare energy in the field to kinetic energy?*

Suggest that we try the simulation now to see if it gives us more expected results.

3 · INVESTIGATE BOND BREAKING AND FORMING WITH A SIMULATION

15 min

MATERIALS: *Breaking/Forming Bonds*, internet-connected device, https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR1.html, https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html, projector with sound

Orient to a simulation. Display **slide E**. Show students how https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR1.html is different from previous simulations. Reiterate that the new simulation has two magnets and the initial kinetic energy of glass marble equivalent *G1* is also adjustable.

Elicit ideas about what we would expect to see in the simulation. Listen for the idea that energy will transfer into the field when a bond breaks, and transfer out of the field when a bond forms. Query students about how these two amounts of energy should compare. If needed, ask students to map to a combustion reaction--do we expect to put more energy into that reaction, or get more out?

See if the simulation meets our needs. Display **slide F**. Share the simulation link with students: https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR1.html. Instruct students to open the simulation and explore it for a minute to see if it reflects our predictions.

ADDITIONAL GUIDANCE

It is important to frame this activity as a true test of the simulation, because students need to recognize that the simulation does have an important limitation--the "bonds" are identical in strength, while real-world bonds are not. If students do not recognize that there is a problem with the simulation, prompt them to think about what we know about the real-life particles after combustion. They have *a lot* of kinetic energy, which this simulation does not show. This will motivate students to think about what might be needed to make the simulation more realistic.

Debrief the initial test. Display **slide G.** Point out to students that when a model does not behave as expected, it is often because it has limitations.

Ask students, *How is this system different from one with real atoms, molecules, and bonds?* Listen for the idea that bonds are not all the same strength. Students may also bring up one or more of the these ideas:

- Atoms have different numbers of subatomic particles.
- Molecules have different combinations of atoms.
- Atoms have different properties, like radius and electronegativity.
- Bonds are different--some are ionic, some are polar, some are nonpolar, some are metallic.

If necessary, leverage ideas about these differences to lead students to the idea that bond strength might be a good place to start in making this simulation more realistic, since we are currently focused on breaking and forming bonds.

Investigate breaking and forming bonds with a second simulation. Display **slide H.** Share the second simulation with students, https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html and make sure they notice the bond strength sliders. Give students a minute to make sure the new simulation meets our needs before starting the investigation. Distribute *Breaking/Forming Bonds*. When students are ready, they should first set the magnets to equal strength, then make one magnet stronger, and then make the other magnet stronger. Remind students that the goal is to determine the differences in energy change, or final kinetic energy, under these different conditions. Instruct students to record their simulation data in *Breaking/Forming Bonds*, and then use the data to answer the prompts below the table. Sample student data may be found in *Breaking/Forming Key*.

Attend to the "wobble." When a bond forms, neither graph immediately levels out. If students are unsure whether to use the high or low number for their energy output, ask, *Does it seem like the numbers are bouncing between the same two values?* Use students' responses to lead the class toward the idea that an estimated average would be best.

ADDITIONAL GUIDANCE	Depending on the availability of internet-connected devices, this investigation can be done individually, in pairs, or in small groups; or, if necessary, as a whole-group activity using the teacher's device and projector.

ALTERNATE ACTIVITY	In addition to the simulation, it may be valuable to have the two magnet marble and ruler system available to students, as well as a second system in which one of the magnet marbles is stronger than the other. Although it is difficult to break the strong bond in this system, it can help give students a physical sense of what is happening, especially for those students who do not connect with the simulation.

4 · DISCUSS AND MODEL ENERGY TRANSFERS

18 min

MATERIALS: *Modeling Energy Changes*, science notebook, https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html, internet-connected device, projector with sound

Analyze investigation data. Display **slide I.** Discuss the three prompts on the slide.

Suggested prompt	Sample student response
*What conditions resulted in a net **increase** in kinetic energy (more kinetic energy transferred out of the system than into it)?* ✱	When the second magnet was stronger than the first magnet. When the bond formed was stronger than the bond broken.
*When did we get a net **decrease** in kinetic energy (less kinetic energy transferred out of the system than into it)?*	When the first magnet was stronger than the second magnet. When the bond broken was stronger than the bond formed.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

Students' prior work with *energy conservation* thinking has included tracking energy in Earth systems in *Polar Ice Unit* and calculating the amount of particle-level kinetic energy (thermal energy) transferred between different amounts of matter. Their first work with *energy conservation using fields* was in *Electrostatics Unit*, where students used a simulation to see that the kinetic

Suggested prompt	Sample student response
Where is that energy coming from or going to?	Accept all student ideas.

Track energy changes when bonds break and form. Suggest that we track all the energy in the various graphs to see if we can figure out the transfers in this bond breaking/forming system.

Display **slide J** and distribute *Modeling Energy Changes*. Have students orient to Scenario 1 on the handout. Say, *Let's run one condition together to see if we can figure out what is going on with energy in this system.* Present https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html and set the conditions to match those on the slide. Tell students to watch as the simulation runs and to draw small stars on the screenshot where the energy changes occur. Then elicit ideas from students.

Suggested prompt	Sample student response
When is there the most kinetic energy?	Before the bond breaks, and after the bond is formed.
When is there the least kinetic energy?	Between the bond breaking and the bond forming. When the metal marble is right in the middle, between the two magnets.
When is energy in the field at its greatest? At its least?	The maximum energy is between the bond breaking and the bond forming. The minimum energy is at the beginning and the end.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students connect relative energy transfer when bonds are broken and formed to bond strength. (DCI: PS1.B.1; CCC: 5.2)
- Students identify transfers of energy between particle motion and fields between particles when bonds are broken and formed. (DCI: PS1.B.1; CCC: 5.2)
- Students use evidence from the computational model to support their ideas. (SEP: 2.3; DCI: PS1.B.1, PS3.C.1; CCC: 5.1, 5.2)

What to do: If students struggle to identify that there are differences in the net kinetic energy of the system depending on the strengths of the bonds that are broken and formed, use https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html to demonstrate this. Keep track of the net kinetic energy as a result of two conditions: Magnet *M1* strength is greater than Magnet *M2* strength, and Magnet *M1* strength is weaker than Magnet *M2* strength.

Building toward 6.A.1 Develop and revise models based on evidence and use these to present and compare an argument for an explanation of where energy is transferred to and from and why energy is conserved within a system when bonds break and form. (SEP: 2.3, 7.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.1, 5.2)

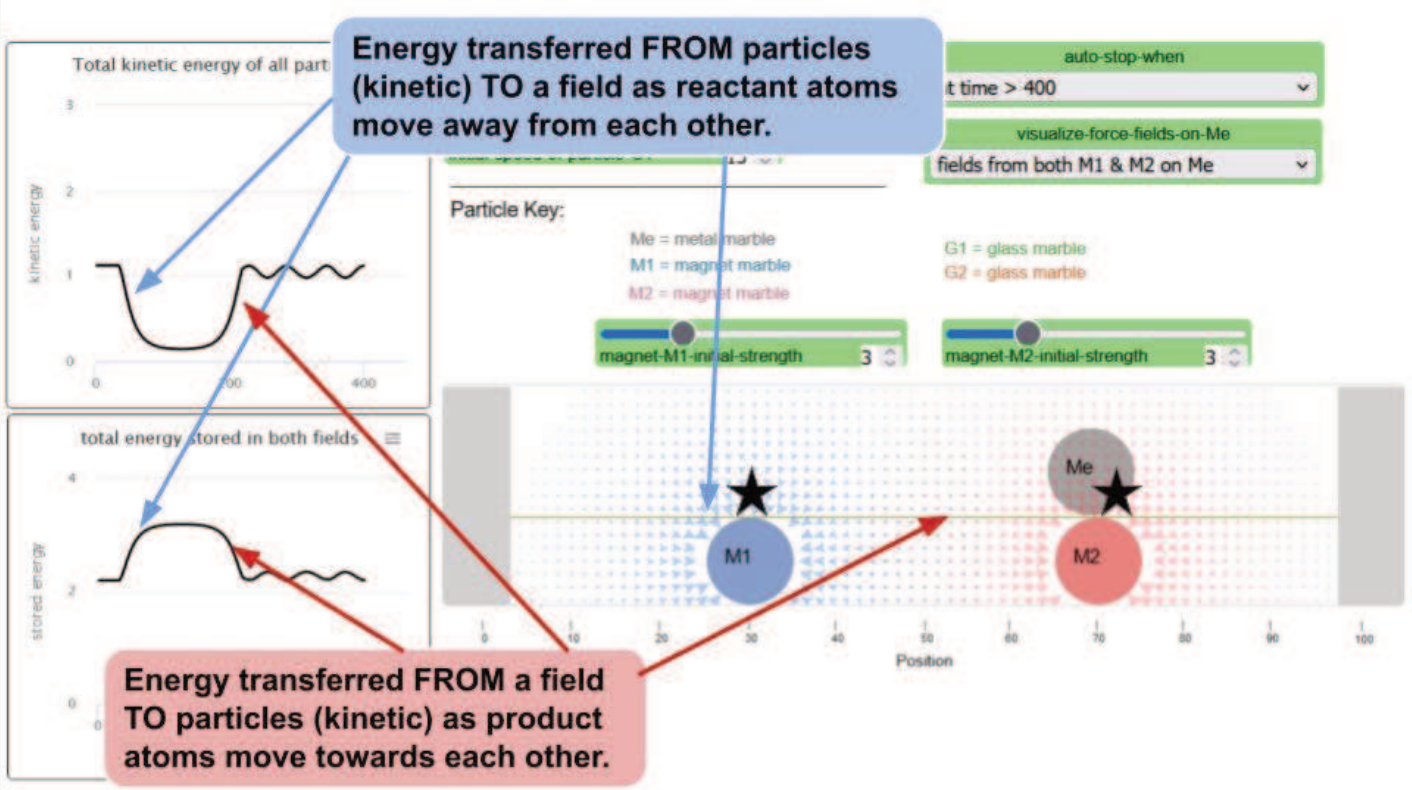
Say, *Now let's think about the time and space **between** breaking and forming. What is going on with these weird humps and dips in our graphs?*✱

energy of a charged particle and the energy stored in the field went up or down by the same amount as the particle moved through space. This lesson is the first experience students have with tracking the total amount of energy stored in multiple fields and the total kinetic energy of multiple particles over time in support of arguing for the idea that *total energy in the system does not change*. (CCC: 5.1)

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Leveraging A/B partners later in this activity supports emergent multilingual learners, along with all students, by ensuring that students bear some intellectual responsibility. It also emphasizes that all students' ideas matter.

Suggested prompt	Sample student response
What do we notice about how the kinetic energy and energy in the field relate to each other?	When one is high, the other is low, and vice versa.
How can we use these graphs to support an argument that energy is conserved throughout this entire process?	The total energy doesn't change.
What have we figured out about forces in bond systems that can explain this big hump of energy stored in the field?	There are attractive forces between the magnets, or between atoms. Maybe because the metal marble is attracted to two magnets there? That is where the metal marble is farthest from both magnets and the forces are weakest.



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

Identify where forces are balanced. Continue annotating the screenshot on **slide J** as a class as students annotate *Modeling Energy Changes*. Point out the maximum energy stored in the field on the graph, between the space where an old bond finishes breaking and a new bond starts forming. Explain that this also corresponds to where the forces from both fields are *balanced*.

Determine activation energy from the graphs. Focus students on the initial energy in the field (~2.1) and the "highest" energy in the field (~3.1). Ask, *How much energy does this jump on the graph represent? What does that tell us about how to start this reaction?* Listen for ideas about the energy needed to start the reaction. Have students annotate their graphs and, if needed, practice identifying this "jump-start" energy with a higher initial strength in the simulation. Ask students if the energy in the field ever returns to this level again. Students should recognize that it decreases when the new bonds form.

Explain that the name for that minimum amount of energy required for a chemical reaction to occur is *activation energy*. This point in the graph can help us predict whether a bond will break when energy is added to the system. Encourage students to add *activation energy* to their Personal Glossaries.

ADDITIONAL GUIDANCE

Identifying the activation energy in this context helps students understand stability and change in chemical reactions in terms of forces, energy, and where the matter is located in space. This also connects to an important part of DCI element PS1.A.4 that was the focus of Lesson 4: *Stable forms of matter are those in which the electric and magnetic field energy is minimized. 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*. While this DCI element is not the primary focus of the next assessment opportunity, it is something you can ask a follow-up question about at the end of the lesson, or as home learning.

Consider energy conservation. Display **slide K.** Ask, *What happens to the total energy across these two graphs? Is energy conserved?* Give students a minute to exchange ideas with a partner and then share with the class. Invite a student or two to explain their thinking at the board. Listen for these ideas:

- When energy stored in the field is the highest, kinetic energy is the lowest.
- Changes in kinetic energy correspond to energy going into or out of the field.
- As one goes up by a certain amount the other goes down by the same amount, and vice-versa.

Press students to explain whether energy is lost or gained in this reaction. Listen for ideas about energy conservation, and draw numbers from the graphs in the simulation to check students' ideas. Have students complete numbers 3 and 4 on *Modeling Energy Changes* for Scenario 1.

Transition to interpreting energy transfers during reactions of unequal bond strengths. *Now let's look at the other two conditions, where the magnets are not of equal strength.*



Model energy changes using A/B partners. Display **slide L**. Have students work in pairs to annotate energy transfers in the remaining two models on *Modeling Energy Changes*. Each student should annotate one of the two models, using the model completed as a class as an example.

After each student has completed their model, partners should share and explain their reasoning. While one student shares, the other student asks clarifying questions and, once partners are in agreement, the student who is listening adds the annotations to their handout. Then partners reverse roles. In this way, both students end up with a completed *Modeling Energy Changes* and with practice sharing and critiquing an explanation.

ASSESSMENT OPPORTUNITY	**What to look/listen for in the moment:** • Students annotate their models to show the points in time when the kinetic energy of particles decreases and total energy stored in the field(s) increases. (SEP: 2.3; CCC: 5.2) • Students annotate their models to show the points in time when the kinetic energy of particles increases and total energy stored in the field(s) decreases. (SEP: 2.3; CCC: 5.2) • Students annotate their models to show that as particles change position, the energy stored in the field changes. (SEP: 2.3; DCI: PS3.C.1) • Students argue that the total energy in the system does not change. (SEP: 7.4; CCC: 5.1) **What to do:** Encourage students to use the energy graphs in the screenshots on *Modeling Energy Changes* to map the changes in energy to where bonds break and form. Students may also benefit from running https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html using the conditions found on the handout. You may collect *Modeling Energy Changes* and give students feedback based on *Modeling Energy Key*. Focus this feedback on the strength of students' arguments about changes in energy, as well as their understanding of the relationships between energy and particle position/motion. Allow students to revise their work in response to your feedback. **Building toward 6.A.2** Develop and revise models based on evidence and use these to present and compare an argument for an explanation of where energy is transferred to and from and why energy is conserved within a system when bonds break and form. (SEP: 2.3, 7.4;DCI: PS1.B.1, PS3.C.1; CCC: 5.1, 5.2)
ALTERNATE ACTIVITY	If time permits, or if you are noticing that students are struggling to complete *Modeling Energy Changes* with strong explanations of matter and energy changes, encourage students to work together to complete both models and all of the questions.

5 · NAVIGATE

2 min

MATERIALS: None

Navigate. Display **slide M**. Say, *We have shown what is happening when bonds break and form in a simulation. How does this help us explain the energy we get from combusting fuels?* Listen for:

- The bonds that form in combustion must be stronger than the bonds that break.
- More kinetic energy is being transferred out of the system of molecules than is going into it. This is because of the greater amount of energy being transferred out of the field(s) than into the field(s).

Ask students, *Do all reactions release energy like combustion reactions--can anything be a fuel? Are all fuels the same? What does that have to do with bond strength?* Accept all responses. Suggest that since this point is unclear, it might be good to dig into bond strength a little more.

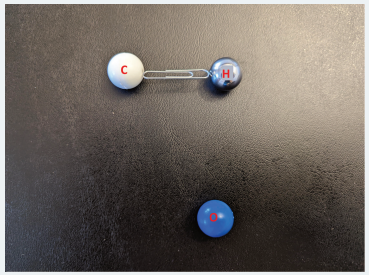
LESSON 7: How can fuels release different amounts of energy when they all have bonds breaking and forming?

PREVIOUS LESSON *We used a computer model of the magnet marble system to collect data on the kinetic energy of particles and the energy stored in fields as bonds break and form. We used the data to develop arguments for where energy is being transferred to/from and how energy is conserved in the process.*

THIS LESSON

INVESTIGATION

2 days



We revisit everything we have figured out about how energy is involved in bond breaking and formation. We also revisit past knowledge about bond types to help us make sense of how the types of atoms being bonded affect the bond energy. We then use these different bond energies to create a visual and mathematical representation of the energy transferred into fields to break the reactant bonds in methane combustion and the energy released when forming its products. The visual representation helps us make sense of diesel's higher energy released values as compared to gasoline. We also see that in some reactions more energy is transferred into than out of the system. We end our class revisiting the DQB to see what questions we can answer.

NEXT LESSON *We will model how carbon-based fuels provide energy. We will examine how much carbon dioxide is released when different fuels and vehicles are used. We will update our Progress Tracker. We will check in on our DQB and complete a mid-unit assessment on cold packs or hot packs.*

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

7.A Respectfully provide critiques based on scientific arguments to determine that the cause of varying energy transfer from reactions is due to differences in energy stored in the fields between bonded atoms. (SEP: 7.3; DCI: PS3.C.1; CCC: 2.2)

7.B Apply scientific reasoning and models to claims to consider the relative scale of energy transfer into and out of fields in a closed system as the atoms in molecules change relative position. (SEP: 6.4; DCI: PS3.B.3; CCC: 3.1, 5.1)

WHAT STUDENTS WILL FIGURE OUT

- The number of bonds broken and formed cannot fully explain the energy transferred out of a combustion reaction.
- High-electronegativity elements tend to form stronger bonds than low-electronegativity elements.
- More energy must be transferred to the field to break a strong bond compared to a weaker bond and more energy is transferred from the field when a strong bond is formed.
- Reactions in which energy appears to be released are called exothermic and reactions in which energy appears to disappear are called endothermic.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min	✓	**NAVIGATE** Have students work in pairs to update their Progress Trackers. Lead a discussion to consider possible explanations for energy being released into the surroundings.	A-C	
2	8 min		**IDENTIFY AND CONSIDER BOND DIFFERENCES** Lead a whole-class discussion to remind students about chemical bonds. Have students turn and talk with a partner to consider differences between C-H, C=O, C-C, O-H, and O=O bonds. Demonstrate differences using magnet marbles and paper clips.	D-F	*Electronegativities and Bonds*
3	7 min		**MODEL DIFFERENT BONDS** Organize students into pairs to complete the Bond Strength Investigation.	G-H	Bond Strength Investigation
4	8 min	✓	**ENGAGE IN ARGUMENT ABOUT THE RESULTS AND APPLY AN ENERGY LENS** Have students turn and talk with a partner to engage in argument. Lead a whole-class discussion to apply particle-level and energy transfer thinking to the investigation results.	I-K	
5	14 min		**CONSIDER BOND STRENGTH AND ENERGY TRANSFER** Have students complete a Stop and Jot activity to begin thinking about the cumulative effects of multiple bonds breaking and forming.	L-O	*Combustion of Methane*, calculator, *Bond Energy Cards*
					End of day 1
6	8 min	✓	**NAVIGATE** Have students compare their calculated energy transfer of methane against the established value.	P-Q	*Combustion of Methane*
7	20 min	✓	**PREDICT AMOUNTS OF ENERGY RELEASED** Support students as they work in pairs to explain the predicted energy released values of gasoline and diesel.	R-S	calculator, *Fuel Energy Released*, *Bond Energies*
8	11 min		**DEVELOP UNDERSTANDING OF ENDOTHERMIC REACTIONS** Have students turn and talk to determine the transfer of energy during gasoline production.	T-U	*Bond Energies*
9	6 min		**REVISIT THE DRIVING QUESTION BOARD** Lead a class discussion to briefly reflect on all the questions we have answered so far to motivate putting the pieces together in the next lesson.	V	DQB
					End of day 2

Lesson 7 • Materials List

	per student	per group	per class
Bond Strength Investigation materials	• safety glasses with side shields • science notebook	• 2 stronger magnet marbles • 2 regular magnet marbles • 2 metal marbles • 2 paper clips	
Lesson materials	• science notebook • *Electronegativities and Bonds* • *Combustion of Methane* • calculator • *Fuel Energy Released* • *Bond Energies*	• calculator • *Bond Energy Cards* • *Bond Energies*	• DQB

Materials preparation (40 minutes)

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

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

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

Electronegativities and Bonds combines two references students have from *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, found in Lessons 5 and 8. You may distribute this reference if students no longer have copies of the originals.

Have the DQB visible on day 2.

Day 1: Bond Strength Investigation

- **Group size:** 4-5 students
- **Setup:** Gather materials for the investigation. Use information contained in *Building Marble Equipment* from Lesson 4 to ensure materials are set up correctly.
- **Notes for during the lab:** It can be helpful to use a tray for catching the marbles.
- **Safety:** Ensure that students do not attempt to open the magnet marbles. Students could pinch their fingers or experience health emergencies if the magnets are swallowed. In addition:
    - Pick up any marbles off the floor to prevent slips, trips, and falls.
    - Make sure there are no fragile items in the projectile trajectory zone.
    - Wear sanitized safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of the activities.
    - Wash hands with soap and water upon completing the hands-on activity.
- **Disposal:** Do not dispose of any materials.
- **Storage:** Store all materials in a cabinet for future use.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS3.C.1 Relationship Between Energy and Forces:** When two objects interacting through a field change relative position, the energy stored in the field is changed.
- **PS3.B.3 Conservation of Energy and Energy Transfer:** 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.

Crossout explanation: Students have been building the first of these elements since Lesson 4 and will use similar ideas again in Lesson 11 to explain energy transfer in nuclear fission. The second element was previously introduced in *Polar Ice Unit* in the context of conduction; here it is applied to chemical reactions for the first time. Students will quantify kinetic energy in OpenSciEd High School Physics in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)* and consider energy storage in compression of a spring in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*.

Students return to their understanding of electronegativity from *Space Survival Unit* to try to explain whether differences in bond strength can account for the differing amounts of *energy transfer using scale-scale mechanisms* in different combustion reactions (CCC: 2.2). They determine that electronegativity does not fully explain trends in bond strength, but it provides a solid base for understanding why bonds might be different. Students use different-strength magnet marbles and a metal marble to gather more evidence to *evaluate arguments, including by critiquing those of a hypothetical student* (SEP: 7.3). This is all centered around energy storage in the field changing as position changes (DCI: PS3.C.1). Students discuss the investigation results and apply energy transfer thinking to explain why *differences in bond strength affect the amount of energy needed to break or form bonds*. Students put all of their discussions together to explain how the *differences in bond strengths (energy stored in the field)* affect the *amount of energy transferred out of the system* (SEP: 6.4; DCI: PS3.B.3; CCC: 3.1, 5.1).

In this lesson, students will co-construct definitions for the following terms, which they should add to their Personal Glossaries: *net bond energy* (or *net energy transfer*), *exothermic reaction*, and *endothermic reaction*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

In *Space Survival Unit*, students co-constructed a definition for *electronegativity* in their Personal Glossaries. Students will encounter this term again in this lesson. If students do not recall what it means, point them back to their Personal Glossaries and take a moment to discuss the term as a class.

Where We Are NOT Going

All interactions between particles involving electrostatic forces (ionic and covalent bonds, hydrogen bonds, intermolecular forces, etc.) display similar energy transfers when "broken" or "formed" as the covalent bonds in this lesson. The energetics of interactions not traditionally classified as "bonds" are outside the bounds of this unit, but the same model can be applied to explain phenomena like the cooling effect of sweat evaporating off of skin.

Enthalpy is the thermodynamic quantity closely associated with what we refer to as energy in this unit. However, the strength of bonds involved in a reaction is just one of many factors that affect enthalpy change, such as temperature and pressure. The most accurate enthalpy calculations include consideration of pressure and volume, or alternatively use Hess's law and the enthalpy of formation for each compound in a reaction to more carefully determine enthalpy. This thinking is beyond the bounds of the NGSS and is not addressed in this or any other OpenSciEd High School unit. Instead, we characterize exothermic reactions as those that, on net, release energy (i.e., cause a temperature increase) and endothermic reactions as those in which, on net, energy transfers into the system.

Even though students begin to make sense of the energetics of bonds breaking and forming together in this lesson, they will not address all of the factors that affect the experimentally measured enthalpy of combustion of methane, octane, and dodecane. Examples of these additional factors include pressure, state of matter, temperature, and resonance. Given this, students will be using the bond energies (bond enthalpies) as opposed to the enthalpies of formation due to the application of Hess's law being beyond the scope of the cited DCI in this lesson.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

8 min

MATERIALS: science notebook

Add to Progress Trackers. Say, *Over the last couple of lessons, we have figured out a lot about how energy and forces relate to forming and breaking bonds. We should capture some of these ideas in our Progress Trackers before moving on. Let's take time to do that now.* Display **slide A.** Give students four minutes to update their Progress Trackers. A sample Progress Tracker entry is shown and can also be found in *Progress Tracker Key* in Lesson 2.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	**Engineering implications** Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
We used a sim to figure out that, at least in the marble system, it seems like we get more energy out of the reactions than we put in when the bond that forms is stronger, and when the bond that breaks is stronger it takes more energy to start the reaction than we get out.	Carbon-based fuels must have high energy released values because of the bonds that break compared to the bonds that form.	Avoid: Excess trips when possible. Shift: To fuels with higher energy released and lower carbon dioxide emissions. Improve: Whatever fuel we need, it would seem like it should have stronger bonds formed than broken.

Share Progress Tracker entries. Display **slide B.** Ask, *What ideas did you add to your Progress Tracker?* Look for students to share the following ideas:

- When a bond forms, attractive forces between the atoms forming that bond pull the atoms together.
- These forces result in an increase in particle-level kinetic energy.
- Bond forming speeds up particles in the system.
- Energy is transferred out of a field when bonds form.
- Energy is transferred into the field when bonds break.
- Some bonds are stronger, which requires more energy to break AND releases more energy when formed.

Apply previous day's learning to gasoline and diesel combustion. Say, *So what I hear you saying is that breaking bonds takes energy as an input, but forming bonds transfers energy out of the field. But how does that help us understand the role of fuel within our vehicle cylinder system? Let's try to make sense of this.* Display **slide C**. Lead a class discussion to apply the sensemaking of Lesson 6 to the gasoline combustion reaction system, using the following prompts:

Suggested prompt	Sample student response
How is the combustion reaction system shown on the slide similar to the "marbles" in the sim?	Bonds are broken and formed. Energy is probably absorbed and released. The bonds are different, like the different magnet marbles.

Suggested prompt	Sample student response
How is it different?	There are many bonds that are breaking and forming at once. There are different types of bonds (single, double).
As the gasoline combusts, how do we know energy transfers out of the reaction?	We see energy transferring out because the piston lowers when fuel combusts. The piston lowers because the air heats up from the energy coming out of the reaction.
What might this outward transfer mean for the bond strengths of the reactants versus the products?	Like we saw last class, since energy is leaving that must mean the product bonds are stronger. The bonds of the products are stronger, because if they were weaker we would observe energy transferring into the field.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students suggest cause-and-effect relationships that rely on smaller-scale mechanisms. (CCC: 2.2)
- Students argue that the transfer of energy is the result of relative bond strengths and the consequent energy stored in the fields of the reactant and product bonds. (SEP: 7.3; DCI: PS3.C.1)

What to do: Students should be relatively comfortable with the idea that energy is transferred into the field to break a bond and out of the field when bonds form. Press students to consider how the particle interactions might be different in an actual reaction. Draw comparisons between the magnet marble models and simulations in prior lessons. If students are not drawing the parallels between the models, zoom in on the molecule of gasoline and ask students to show where the magnet is pulling.

Building toward 7.A.1 Respectfully provide critiques based on scientific arguments to determine that the cause of varying energy transfer from reactions is due to differences in energy stored in the fields between bonded atoms. (SEP: 7.3; DCI: PS3.C.1; CCC: 2.2)

Say, *OK, so we know energy transfers out of the gasoline reaction. We also have seen that in order for this to happen, the bonds of the products must be weaker than the bonds of the reactants. But is there anything else we could do to further support this idea? Let's take a closer look at the bonds breaking and forming in these reactions.*

2 · IDENTIFY AND CONSIDER BOND DIFFERENCES

8 min

MATERIALS: *Electronegativities and Bonds*

Compare types of bonds broken versus formed. Display **slide D**. Say, *Here are the combustion reactions for gasoline and diesel. What are the bonds being broken? What are the bonds being formed?* Have students discuss these questions, and the other prompt on the slide, with their partner. After a few minutes, ask for volunteers to share their ideas.

Suggested prompt	Sample student response
What bonds are breaking?	The fuels have C-C and C-H bonds. Oxygen has two O-O bonds. Oxygen has a double bond between two oxygen atoms.
What bonds are forming?	Water just has O-H bonds. Carbon dioxide has four C-O bonds. CO_2 has two C=O bonds.
Thinking about Electrostatics Unit and Space Survival Unit, is there anything that these models do not show us?	They don't tell us the types of bonds that these are. They don't tell us whether there are any charges. We don't know if they are polar or nonpolar.

Display **slide E** and say, *In Space Survival Unit we spent a lot of time thinking about bonds. Recall that we defined a bond as occurring when atoms pull on some of each other's electrons. We also had some indication from that unit that bonds are different from one another, but we have not reflected on this in awhile.* Have students share what they remember from that unit. Ask students to briefly discuss the prompts on the slide.

Suggested prompt	Sample student response
What were the types of bonds we observed?	Polar, nonpolar, and ionic. Covalent and ionic bonds. Metallic bonds too.
What caused these bonds to be different?	The electrons are shared differently. The strength of pull that each atom has on the other atom's electrons. The atom's electronegativity.

If students do not bring up electronegativity, keep probing what causes bonds to be different. You may wish to present two very different bonds to support students' thinking: for example, show a highly polar hydrogen-oxygen bond and a nonpolar oxygen-oxygen bond and ask students to think about why the electrons behave differently in the two situations.

Compare electronegativities. Display **slide F** and distribute *Electronegativities and Bonds.* Lead a class discussion using the prompts on the slide.

Suggested prompt	Sample student response
Based on their electronegativity differences, how would we classify each type of bond?	C-H, C-C, O=O are nonpolar. O-H and C=O are polar.

Suggested prompt	Sample student response
How might we use this information to predict which of these bonds are the strongest?	The bonds that are polar are probably the strongest. The bonds with atoms that are more electronegative might be the strongest.

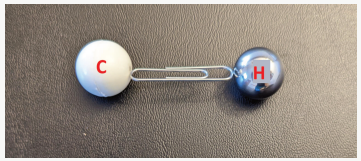
Say, *This is hard to visualize, so let's try to model these interactions using magnet marbles similar to what we have seen over the last couple of lessons.*

3 · MODEL DIFFERENT BONDS

7 min

MATERIALS: Bond Strength Investigation

Start students modeling. Display **slide G** and say, *Let's have different magnets represent different atoms. O can be the strongest magnet since it has the highest electronegativity, C can be the weaker magnet since it has lower electronegativity, and H can be a non-magnet.* Demonstrate how to form a bond with two marbles and a paper clip. Display **slide H** and review safety guidelines before returning to **slide G**.



Organize students into pairs and have a representative from each pair collect the materials. Remind students that each marble represents the nucleus and non-valence electrons of an atom and that the paper clips represent the valence electrons shared between the atoms. Then, explain to students that they will have a few minutes to compare the different bonds by pulling on the different combinations of marbles with a paper clip between them and feeling the force as they interact. Have students record their noticings in their science notebooks, using the prompts on the slide.

Move around the room and listen to the conversations students have as they complete the investigation. The following table summarizes what you might hear from students as they discuss the prompts in pairs.

Suggested prompt	Sample student response
What do you notice about the difficulty of breaking these different bonds?	Bonds involving stronger magnets are harder to break.
What do you notice about how the paper clip interacts with the marbles?	The paper clip sticks to the stronger magnet. If the magnets are the same, the paper clip will stick to one or the other, depending on how the magnets and paper clip are aligned.

ADDITIONAL GUIDANCE

In this lesson, it may seem like the role of electrons in causing repulsion between atoms that get too close has been minimized. If students are confused about how electrons are primarily framed as a cause of attraction rather than repulsion here, have them return to the paper-clip model from *Electrostatics Unit* and *Space Survival Unit* in which electrons do repel, but also are attracted to the nuclei of both their own atom and a bonded atom.

4 · ENGAGE IN ARGUMENT ABOUT THE RESULTS AND APPLY AN ENERGY LENS

8 min

MATERIALS: science notebook

Engage in argument about the results. Display **slide I**. Give students a moment to turn and talk with a partner before hearing the claims and evidence from a few different pairings. ✱ Ensure that the students talk with someone other than their investigation partner from the last lesson step.

Use the following prompts to lead a whole-class discussion. As students share, give them opportunities to respond to and counter each other's claims using evidence. Consider allowing students to write their ideas before sharing if time allows.

Suggested prompt	Sample student response
What did you observe when we modeled with the marbles?	It was harder to break the C=O bond than the C-H bond. The valence electrons were more attracted to the O than the C and more attracted to the C than the H.
Based on your noticings, how would you rank each type of bond, from strongest to weakest?	The order we found was O=O, C=O, O-H, C-C, and the weakest was C-H.

Summarize the discussion. Say, *This is kind of tricky. Let's think more about what is happening between the marbles and paper clips, or atoms and electrons, and see what that can tell us.*

Continue the discussion by focusing on the particles. Display **slide J**.

ALTERNATE ACTIVITY

If these questions are too complex or difficult in sentence form, consider distributing a piece of blank paper to groups of students to draw each of the bonds and their forces: C-O, C-H, and O=O (reactants) and O-H and C=O (products). This multimodal support will benefit students in identifying how matter and energy shift in a bond when a reaction occurs.

Suggested prompt	Sample student response
How can we describe the differences in the forces between these atoms and the electrons they share?	In the bond, both atoms are attracted to the electrons. O pulls the most on the electrons.
Why does this make sense?	O has the highest electronegativity and is represented by the strongest magnet.
Does the pull start only when the atoms are touching?	No, it starts at a distance.
Why does the force acting at a distance make sense?	There are magnets or charges involved.
How do the forces from both atoms on their shared electrons result in the bond being stronger or weaker?	The combined forces from both atoms pull on the shared electrons, influencing how hard it is to pull them apart or break the bond.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Students who are learning English may benefit from some alone time to process the prompts on **slide I** before sharing with a partner. Consider giving students time to stop and jot their responses before sharing verbally with their partners.

Universal Design for Learning: Other students may also benefit from some time to write down their ideas. This supports students' *action and expression* by giving them another form of media to use when respectfully providing arguments about different bond strengths in the field. (SEP: 7.3; DCI: PS3.C.1)

Suggested prompt	Sample student response
How might the amount of energy needed to separate these attractive forces differ in strong and weak bonds?	The stronger the force the stronger the bond, so it will need more energy to break. Weak bonds won't need a lot of energy to break because there is less force holding them together.
How might actual atoms and bonds be different from our marble model?	Real atoms are different sizes. Real atoms are more complex, with different amounts of subatomic particles. Real bonds can be more or less polar, ranging from nonpolar covalent to ionic.

Say, *It seems like we have a pretty good handle on the forces involved. Let's return to thinking about energy transfers and changes.*
Conclude the energy discussion. Display **slide K**. Ask, *Using what we have seen and learned over the last few lessons, what critiques would you offer to a student who provided this answer to the question on the slide? As you and your partner generate these critiques, be sure to consider how they can be phrased for your feedback to be respectful and constructive to this student.* Listen for these ideas:

- Provide feedback in the form of questions or other commonly-used question stems (Have you considered...?).
- Address the idea and not the person.
- The student needs to address which bonds are being broken and which bonds are being formed.
- The student needs to consider the difference between energy transferred into broken bonds and energy transferred out of formed bonds.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use reasoning and evidence to respectfully construct critiques for a hypothetical student's response about which differences in bond strengths would result in energy being transferred out of the field through smaller-scale mechanisms. (SEP: 7.3; CCC: 2.2)
- Students' critiques guide the hypothetical student's thinking to conclude that more energy must be transferred into the field to break a strong bond and transferred out of the field when a strong bond is formed. (SEP: 7.3; DCI: PS3.C.1)

What to do: Encourage students to use evidence from the modeling activity and about electronegativity to support their critiques. Focus on the differences in breaking or forming one type of bond in this activity, as day 2 of Lesson 7 and the navigation into Lesson 8 do more to build thinking about net energy transfer when multiple bonds are involved. Push students to think as much as possible at the particle level in their responses; if necessary, provide sentence stems to encourage cause-and-effect thinking at this scale. Encourage students to target their critiques at the ideas, not the person, and provide feedback around providing praise alongside criticism. This example with hypothetical responses is a scaffold toward Lesson 14 in which students will provide extensive feedback on their classmates' design arguments.

Building toward 7.A.2 Respectfully provide critiques based on scientific arguments to determine that the cause of varying energy transfer from reactions is due to differences in energy stored in the fields between bonded atoms. (SEP: 7.3; DCI: PS3.C.1; CCC: 2.2)

ALTERNATE ACTIVITY	Students will have to give and receive feedback in a structured way in Lesson 14, in addition to less structured moments throughout the unit. You may wish for students to reflect on the type of feedback they gave in this activity. A standard template for self-assessment when giving or receiving feedback may be found in the *OpenSciEd Teacher Handbook: High School Science*.

5 · CONSIDER BOND STRENGTH AND ENERGY TRANSFER

14 min

MATERIALS: science notebook, *Combustion of Methane*, calculator, *Bond Energy Cards*

Assess the validity of a claim about energy transfer. Display **slide L**. Have students turn and talk to discuss the validity of the diesel claim--that diesel transfers more energy than gasoline because you are breaking weaker bonds and forming stronger bonds. Then have a few volunteers share their ideas with the class. Look for these ideas:

- The types of bonds (C-C, C-H) found in gasoline and diesel are the same.
- Since the types of bonds are the same, this doesn't account for the difference in energy released values.
- The number of each type of bond is different between the two reactions.

Focus on diesel bond quantity. Say, *Since the types of bonds broken and formed are the same, I hear you saying that the difference between these reactions is the number of bonds broken and formed. Let's see if we can use the number of bonds to better predict our expected energy transfer with a simpler reaction.*

Display **slide M**. Have students continue to work in pairs to figure out the number of each type of bond found in the methane combustion system. (Methane has a less-intimidating number of bonds to calculate net energy in the next step.)

Quantify the energy of reactants and products in a reaction. Say, *In previous experiments, scientists have been able to measure the amount of energy transferred for each type of bond. This measure is called bond energy.* Display **slide N**. Tell students that you have created cards with specific sizes to visually represent the amount of energy transferred for each bond type. Distribute *Combustion of Methane* and *Bond Energy Cards*. Instruct pairs to draw the number of C-H Bond Energy Cards and O=O Bond Energy Cards for methane combustion and to stack these cards in #1 of *Combustion of Methane*. Next, do the same for the energy transferred out of the fields by collecting the needed number of O-H and C=O cards. Instruct students to stack these in #2 of the table.

Compare the Bond Energy Cards. Once pairs have all of the cards they need, instruct the students to line up the reactant cards and product cards end-to-end in #3. It is okay for students' cards to extend beyond the edges of the page. Then, have students complete prompts #4-7 on *Combustion of Methane*.

Display **slide O**. Use the prompts below to lead a discussion.

Suggested prompt	Sample student response
What do you notice about the sizes of the reactant and product bars?	The energy transferred out from bonds forming is bigger than the energy being transferred in. You get more energy transferring out than you're transferring in.
How much energy must be transferred into the field between a C atom and H atom to break one of those bonds?	413 kJ

Suggested prompt	Sample student response
What about a bond between two carbon atoms or two oxygen atoms?	Carbon is 347 kJ. Oxygen is 495 kJ.
How can we use the individual bond energies to figure out the total energy transferring out of this combustion reaction system?	Add up the energy needed to break each of the bonds and the energy released from forming each of the bonds. Subtract the two numbers to determine the difference.

After discussing the prompts, have students work in pairs to add up the bond energies lined up in #3 and write their calculated value in the box on the handout. Say, *Next class we will see if our mathematical approach matches the net bond energy value that scientists have agreed upon based on their experiments!*

End of day 1

6 · NAVIGATE

8 min

MATERIALS: *Combustion of Methane*

Return to the sensemaking from the previous class. Display **slide P** and ask students to take out *Combustion of Methane*. Have students begin class by discussing the prompts on the slide in pairs. After students have had a minute to discuss, ask for volunteers to share their ideas.

Suggested prompt	Sample student response
How does your amount of energy transferred compare to the established value?	Our amount was different, and we had a positive number (around 824 kJ).
Why might the established value be different from ours?	Maybe we are missing something? Maybe there is something we're not including?
(Highlight to students that values are calculated and measured in different ways, but that our answer is fairly close to the established value. Problematize the negative number.) *Why do you think the established value is negative?*	Maybe because the energy is being transferred out, so it means you are losing that amount of energy. More energy is leaving than entering.
Where did the energy that is transferred out come from?	It moved out of the field when bonds were formed.
Where is it going?	The energy was transferred out of the field and into the air surrounding the field.

ADDITIONAL GUIDANCE

The value shown on **slide P** is the average value for heat of combustion for methane (CH_4) as reported by the National Institute of Standards and Technology's Chemistry WebBook (www.nist.gov).

Analyze energy transfer. When students have finished, say, *Energy transfer in a chemical reaction is dependent on many factors beyond just the type and number of bonds. Although there are tools to account for these factors, we will stay focused on just two: types and numbers of bonds being broken and formed.* Display **slide Q** and lead a class discussion using the prompts to analyze energy transfer.

Suggested prompts	Sample student responses	Follow-up questions
Would this transfer of energy cause the surrounding air molecules in the cylinder system to speed up or slow down?	It would cause them to speed up because the energy is leaving the reaction and going to the air molecules.	*How would this then affect the pressure exerted on the piston in the cylinder system?* *Does matter leave this system? Does energy?*
If you started with 2 moles of methane and 4 moles of oxygen, why would this affect the total energy transferred?	Because there are more molecules taking part in the reaction. More bonds are breaking and forming.	*How much energy would we expect to be transferred if we had 1 mole of methane and 2 moles of oxygen?*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' claims use bond energies and atoms' changing relative positions as evidence to describe and predict energy changes in the system. (SEP: 6.4; DCI: PS3.B.3)
- Students consider the boundaries for the energy transfer out of fields within the closed engine system. (DCI: PS3.B.3; CCC: 5.1)

What to do: Encourage students to support one another in working through the calculations and review the calculations that were completed as a class if necessary. Use the consensus model from Lesson 5 to help students think about where the energy must have come from, and refer back to prior modeling of electric fields as the source of the energy that seems to be coming from nowhere.

Building toward 7.B.1 Apply scientific reasoning and models to claims to consider the relative scale of energy transfer into and out of fields in a closed system as the atoms in molecules change relative position. (SEP: 6.4; DCI: PS3.B.3; CCC: 3.1, 5.1)

7 · PREDICT AMOUNTS OF ENERGY RELEASED

20 min

MATERIALS: science notebook, calculator, *Fuel Energy Released*, *Bond Energies*

Work together to explain the predicted energy released values of gasoline and diesel. Say, *Now we have the tools to fully explain the energy released values of different fuels. Let's return to the two we compared at the start of class: gasoline and diesel. Work with your partner to calculate the expected energy released values of gasoline and diesel.*

Display **slide R**. Distribute *Fuel Energy Released* and *Bond Energies*. Give students about 10 minutes to complete the calculations and debrief questions. ✱

Discuss energy release values. Display **slide S** and carry out a whole-group discussion to explain the predicted energy released values for gasoline and diesel.

✱ ATTENDING TO EQUITY

Universal Design for Learning. *Representation*. Allow students to use math, grid paper, and *Bond Energy Cards* to calculate these values. All of these methods involve quantification practices. If you can, encourage students to share their differing strategies to celebrate that there is no "one right way" to think this through.

Suggested prompt	Sample student response
Based on your calculations, would you predict gasoline or diesel to have a greater energy released value per mole?	Diesel releases more energy than gasoline.
Revise the following claim to reflect a more supported claim: Diesel transfers more energy because you are breaking weaker bonds and forming stronger bonds.	Diesel transfers more energy because more stronger bonds are formed than in gasoline.
Explain why gasoline would be a less ideal fuel choice for semi trucks.	Since gasoline provides less energy per mole, it would generate less force than diesel does. A big truck would be under-powered.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students recognize that the amount of energy provided to the vehicle depends on the relative scale of fuel burned as atoms rearrange. (DCI: PS3.B.3; CCC: 3.1)
- See *Fuel Energy Released Key*.

What to do: Allow students to regularly check their work with others and use *Bond Energy Cards* to support their calculations. Because the focus here is helping students reflect on the scale of fuel burned and connecting it to vehicle type, it is acceptable to work through as much of the calculations as a class as necessary.

Building toward 7.B.2 Apply scientific reasoning and models to claims to consider the relative scale of energy transfer in and out of fields in a closed system as the atoms in molecules change relative position. (SEP: 6.4; CCC: 3.1, 5.1; DCI: PS3.B.3)

8 · DEVELOP UNDERSTANDING OF ENDOTHERMIC REACTIONS

11 min

MATERIALS: science notebook, *Bond Energies*

Predict the amount of energy transferred in gasoline production. Say, *We have learned a lot about predicting how much energy is transferred during combustion reactions. Are all reactions like this? Can we expect that energy will always be transferred out of a system?* Pause and elicit students' ideas.

Display **slide T**. Say, *We saw on the Fuel Data Cards that the source of gasoline is oil. To extract gasoline from oil is a multi-step process. One of these steps is a process called cracking. This is where the larger molecules found in diesel are broken, or cracked, into smaller molecules. Would it be ideal for energy to be transferred out of this system? Let's use what we have learned to predict the energy transfer.* Instruct students to work with a partner to calculate the energy transfer for this reaction.

ADDITIONAL GUIDANCE

If students comment on the apparent change in diesel's chemical formula, remind them that diesel contains a variety of carbon-based molecules of different sizes. Decane ($C_{10}H_{22}$) was chosen here to simplify the work.

Give students a couple of minutes to complete the work in their science notebooks. Example work is shown below.

Energy required to break bonds: (9 C-C * 347 kJ/mol) + (22 C-H * 413 kJ/mol) = 12,209 kJ/mol
Energy released when bonds form: (7 C-C * 347 kJ/mol) + (18 C-H * 413 kJ/mol) + 614 kJ/mol + (4 C-H * 413 kJ/mol) = 12,129 kJ/mol

12,209 kJ - 12,129 kJ = **80 kJ net energy required to break bonds**

✱ ATTENDING TO EQUITY

Scientific language, through the use of root words, can be interpreted more easily if the reader understands the underlying patterns. Making the structure of scientific language visible to all learners is an important equity move because it minimizes the need for memorization and makes the language more familiar.

Then lead a whole-class debrief using the following prompts.

Suggested prompt	Sample student response
Where did you find more energy being transferred?	More energy was transferred in to break the bonds. Less energy was released than transferred into fields.
Does this mean more energy transferred into or out of the reaction system?	The system gained energy because more energy went in than came out.
What would we expect to happen to the temperature if more energy is transferred into the system?	The temperature would go down.

Leverage student surprise or confusion at the result to highlight that reactions can release net energy, causing temperatures to increase, or absorb more energy than they release, causing temperatures to decrease. Name these terms while breaking them down. Reactions that get hotter are *exo*thermic because they send energy out, and reactions that get colder are *endo*thermic because they take energy in.✱

Update Personal Glossaries. Display **slide U.** Have students use these responses to co-construct definitions for *net bond energy*, *exothermic reaction*, and *endothermic reaction.* Give students a moment to add these terms to their Personal Glossaries. *Net energy transfer* may be used instead of *net bond energy*; use the term that resonates more with students.

9 · REVISIT THE DRIVING QUESTION BOARD

6 min

MATERIALS: DQB

ADDITIONAL GUIDANCE

Have the DQB in a place where it is visible to all students from their seats. Due to the short amount of time for this navigation, it will likely not be possible to organize students into a Scientists Circle around the DQB. Alternatively, you could have them stand and gather around the DQB.

Revisit the Driving Question Board. Display **slide V**. Say, *Wow! We have figured out a lot. Let's take a quick look at the DQB to see what progress we have made and where else we still need to go.* Lead a class discussion to have students self-assess what we have figured out and which questions we still need to address.

Students might suggest:

- In Lesson 2, we addressed questions about gasoline and engines.
- In Lesson 3, we saw how diesel is combusted in diesel engines.
- In Lessons 4-7, we made sense of why energy is transferred out of combustion reactions.

Suggest that the class is in a good spot to start putting these different ideas together.

Additional Lesson 7 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HS.N-Q.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and interpret the scale and the origin in graphs and data displays~~.

Students work to quantify and scale up energy transfer for different exothermic and endothermic reactions. The teacher provides additional support for moving between number of bonds, energy transfer into and out of the system, and then net energy transfer. Students must consider multiple units including number of bonds and bond energy.

LESSON 8: How does our understanding of carbon-based fuels inform our decision-making?

PREVIOUS LESSON

We used past knowledge to make sense of the different bond energies that are observed in different types of bonds. We used these bond energies to create a visual and mathematical representation to figure out why some reactions lead to energy transferring out of the system. This knowledge helped us figure out why diesel has higher energy released values than gasoline. Then, we looked at a reaction where more energy is transferred in than out. We ended our class by revisiting the DQB.

THIS LESSON

PUTTING PIECES TOGETHER

3 days





We develop a Gotta-Have-It Checklist to explain why carbon-based fuels like gasoline provide energy. We model this in pairs and build a class consensus model. We apply our model to different fuels and examine how much carbon dioxide is released when different fuels and vehicles are used. We update our Progress Tracker. We check in on our DQB and complete a mid-unit assessment on cold packs or hot packs.

NEXT LESSON

We will evaluate arguments about electric vehicles. We will analyze images of the components found inside different batteries. We will collect data on the voltages produced by different metal electrodes. We will analyze data on the current produced by different electrolytes.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1



WHAT STUDENTS WILL DO

8.A Develop a model based on evidence to illustrate energy transfer into or out of a chemical reaction system depending on energy transfer into and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)

8.B Use mathematical models to show that matter is conserved during fuel combustion and to support claims about fuel efficiency in vehicles and the impacts of carbon-based fuel use. (SEP: 4.1; DCI: ESS3.B.1; CCC: 5.1)

WHAT STUDENTS WILL FIGURE OUT

- All fuels release energy when they are burned because the total bond energy of the products is greater than the total bond energy of the reactants. We can use this to explain the behavior of different fuels.
- The amount of carbon dioxide produced by fuel combustion is related to the number of carbon atoms in the fuel. All carbon-based fuels emit large amounts of carbon dioxide when burned.
- In cold packs, energy transfers in and out of fields result in a temperature decrease. In hot packs, energy transfers in and out of fields result in a temperature increase. This applies even when dissolution is the main process.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		**NAVIGATE** Have students turn and talk with a partner about what we figured out last lesson. Lead a class discussion to share their responses.	A-B	
2	16 min	✓	**DEVELOP A GOTTA-HAVE-IT CHECKLIST** Help students individually brainstorm model ideas on sticky notes. Lead a Consensus Discussion to develop the Gotta-Have-It Checklist.	C-E	3x3 sticky notes, markers, Gotta-Have-It Checklist poster, chart paper, chart paper markers
3	8 min	✓	**MODEL WITH A PARTNER** Organize students into pairs and have them develop a model on a whiteboard.	F	whiteboard, dry-erase markers, Gotta-Have-It Checklist poster
4	3 min		**SHARE PARTNER MODELS** Have two pairs form a larger group to compare models.	G	whiteboard models, dry-erase markers
5	14 min		**BUILD A CLASS CONSENSUS MODEL** Gather students in a Scientists Circle to develop a class consensus model.	H	whiteboard models, Gotta-Have-It Checklist poster, chart paper, chart paper markers
					End of day 1
6	6 min		**EXPLAIN DIFFERENT FUELS** Have students individually explain a fuel of their choice using the class consensus model.	I	class consensus model from day 1
7	8 min		**MAKE COMPARISONS ACROSS FUELS** Lead a class discussion about similarities and differences among the fuels.	J-K	class consensus model from day 1
8	17 min	✓	**CALCULATE CARBON DIOXIDE EMISSIONS** Have students work with a partner to calculate carbon dioxide emissions for a fuel of their choice.	L-M	*Calculating Carbon Emissions*
9	9 min	✓	**DEBRIEF CALCULATIONS AND UPDATE PROGRESS TRACKERS** Debrief the calculations as a class, then have students individually update their Progress Trackers.	N-O	*Calculating Carbon Emissions*
10	5 min		**IDENTIFY QUESTIONS WE HAVE ANSWERED** Have students individually identify which DQB questions we have made progress on.	P	*Our DQB Questions*
					End of day 2
11	8 min		**SHARE DQB QUESTIONS WE CAN ANSWER** Have students share their DQB evaluations with a partner. Gather students in a Scientists Circle to share answers to DQB questions.	Q-S	*Our DQB Questions*, sticky notes, colored marker, DQB
12	5 min		**INTRODUCE THE PHENOMENON FOR THE TRANSFER TASK** Introduce instant hot and cold packs as a new phenomenon to consider. Lead a discussion to clarify understandings from *Cold Pack Scenario* and *Hot Pack Scenario*.	T-W	*Cold Pack Scenario* or *Hot Pack Scenario*, instant cold pack, instant hot pack

Part	Duration		Summary	Slide	Materials
13	8 min		**CONDUCT COLD/HOT PACK INVESTIGATION** Discuss safety considerations for the Cold Pack and Hot Pack Investigations. Organize students into groups of five to conduct the investigations.	X-Y	Cold/Hot Pack Investigation
14	24 min		**COMPLETE MID-UNIT ASSESSMENT** Have students individually complete *Cold Pack Assessment* or *Hot Pack Assessment*.	Z-AA	*Cold Pack Assessment* or *Hot Pack Assessment*, *Cold Pack Scenario* or *Hot Pack Scenario*

End of day 3

Lesson 8 • Materials List

	per student	per group	per class
Cold/Hot Pack Investigation materials	• science notebook • sanitized indirectly vented chemical splash goggles • non-latex apron • nitrile gloves	• 100-mL beaker with 25 mL distilled water • thermometer (non-mercury) • stirring rod • prepared sample of 5 g potassium chloride or calcium chloride • *Hot-Cold Pack Instructions*	
Lesson materials	• 3x3 sticky notes • markers • science notebook • *Calculating Carbon Emissions* • *Our DQB Questions* • sticky notes • colored marker • *Cold Pack Scenario* or *Hot Pack Scenario* • *Cold Pack Assessment* or *Hot Pack Assessment*	• whiteboard • dry-erase markers • whiteboard models	• Gotta-Have-It Checklist poster • chart paper • chart paper markers • class consensus model from day 1 • DQB • instant cold pack • instant hot pack

Materials preparation (40 minutes)

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

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

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

Have the DQB easily accessible to students. Update *Our DQB Questions* with all questions from the DQB.

Make space for a Scientists Circle on days 1 and 3.

Prepare two pieces of chart paper with the following titles:

1. Gotta-Have-It Checklist
2. How does burning a carbon-based fuel (like gasoline) provide energy to make a piston move?

There are three assessment documents for students. Two of these have alternate versions.

- *Cold Pack Scenario* and *Hot Pack Scenario* present the scenarios for the assessments; students will read one of the two scenarios. These documents were separated from the assessments so that students can engage with their scenario before the built-in investigation.
- *Hot-Cold Pack Instructions* contains the instructions for carrying out each investigation.
- *Cold Pack Assessment* and *Hot Pack Assessment* contain the transfer tasks. Students should complete the assessment that corresponds to the scenario they read and the investigation they carry out.

Have an instant cold pack and/or instant hot pack to demonstrate to students before the assessment.

Day 3: Cold/Hot Pack Investigation

- **Group size:** 5 students
- **Setup:** Gather materials for the investigation. In addition:

    - Prepare a weighing dish for each group with 5 g potassium chloride or 5 g calcium chloride.
    - Prepare a 100-mL beaker for each group by filling it with approximately 25 mL water.
    - 3 g of either substance may be used if supplies are short, although the temperature changes will be less noticeable (particularly in the endothermic process).
    - Either anhydrous or hydrated calcium chloride may be used, although anhydrous calcium chloride is recommended due to its greater temperature change in solution.
- **Notes for during the lab:** Students will pour the powder into the beaker and stir in order to speed the reaction. Remind students not to stir with the thermometer.
- **Safety:** Highlight safety guidelines related to use of chemicals, including wearing goggles, not tasting chemicals in the lab, and washing hands well. In addition:
    - Make sure all laboratory occupants are wearing sanitized indirectly vented chemical splash goggles, non-latex aprons, and nitrile gloves during the setup, hands-on, and takedown portions of the activity.
    - Know the location of the A-B-C fire extinguisher, fire blanket, fire alarm, eyewash, and shower and be able to reach them within 10 seconds. Teachers should receive annual training so that they know how to use each of these items. If district policy prohibits the use of a fire extinguisher, in the event of fire, evacuate the room, close the door, and pull the fire alarm.
    - Review the SDS before using potassium chloride and calcium chloride, and make students aware of all hazards.
    - Secure loose clothing, remove loose jewelry, wear close-toed shoes, and tie back long hair.
    - Remind students to use caution in working with glassware--broken glass creates sharps which can cut skin.
    - Remind students to never taste chemicals being used in activities.
    - Make sure students are instructed on how to appropriately dispose of or store salt solutions.
    - Once the activities are completed, students are to remove their personal protective equipment and wash their hands with soap and water.
    - Practice the investigation or demonstration before conducting it with students.
- **Disposal:** All substances can be rinsed down the drain. Rinsed-out beakers may be used across sections.
- **Storage:** Keep containers tightly closed to prevent caking and undesired reactions. Avoid storage with strong oxidizing agents, like nitrates.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.A.4 Structure and Properties of Matter:** Stable forms of matter are those in which the electric ~~and magnetic~~ field energy is minimized. 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.
- **PS1.B.1 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.
- **ESS3.B.1 Natural Hazards:** ~~Natural hazards and other~~ geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations.

Crossout explanations: Magnetic fields are explicitly considered in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)* and *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)* and are not discussed in this unit, except obliquely as students use magnet marbles to model bonding. They previously explored reaction rates in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. Students focused on natural hazards in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, but here they add important ideas about how scaling up individual decisions about vehicles can have significant impacts on the livability of the world due to the carbon dioxide emissions that might be released.

Students build on work from Lessons 1-7 to *develop* complex energy transfer *models that explain* how burning carbon-based fuels provides energy for moving pistons (SEP: 2.3). This requires *tracking energy flows within, into, and out of a system* (CCC: 5.2). Students are using disciplinary core ideas built throughout the first lesson set, but applying them to track energy through all the matter changes that occur in combustion of a carbon-based fuel. They apply this thinking again on the mid-unit assessment on day 3. This assessment uses the phenomenon of hot packs and cold packs and supports students in figuring out how these processes work, even though they do not involve chemical reactions.

On day 2, students *analyze data using mathematical models*, using *matter conservation*, to determine and explain carbon dioxide released in carbon-based fuel combustion (SEP: 4.1; CCC: 5.1). Building on thinking in Lesson 5 about the implications of resources on the human population, students consider the impacts of all people on Earth continuing to use fuels that release so much carbon dioxide.

In this lesson, students will encounter the following terms, which you should help them understand and add to their Personal Glossaries: *lattice energy* and *energy of hydration*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Although students use stoichiometric thinking on day 2 of this lesson with a focus on carbon dioxide, they are not required to do gas stoichiometry. The focus is on considering the implications of conservation of matter (carbon) on human populations.

Students use some quantitative thinking about bond energies in their consensus modeling, but they are not required to do bond energy calculations on the mid-unit assessment task because these ideas are beyond the bounds of the NGSS. Information about these energies' equivalents in dissolution is provided primarily to support students who strongly connected to the mathematical representations in Lesson 7.

Because the focus in this unit is on energy changes in chemical processes, you may provide feedback around students' use of words like *atom* when describing the ions in the assessment task or *bonds* to describe intermolecular forces, but do not score against students on these points.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

4 min

MATERIALS: None

Think back to what we figured out last lesson. Display **slide A**. Have students turn and talk with a partner about the prompts on the slide, then discuss as a class.

Suggested prompt	Sample student response
What did we figure out last lesson?	We can calculate the energy changes in a chemical reaction by comparing bond energies of reactants and products. The total energy (stored in electric fields and kinetic energy of particles) is conserved in a chemical reaction.
What can the ideas we figured out tell us about how fuels work?	When fuels burn, more strong bonds must be forming than breaking. The bond energies show us this. We can calculate the energy released when fuels burn.

Move from a focus on magnets to fuels. Say, *We have spent quite a while thinking about magnets, and last lesson we shifted back to thinking about real fuels.* Display **slide B** and ask students to briefly compare manipulating magnets to carbon-based fuel combustion. Listen for these ideas:

- Bonds break and form in both processes.
- The combustion reaction is way bigger and more complicated.

ADDITIONAL GUIDANCE

If students do not talk about bonds breaking and forming, pause. Show and run the simulation https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html. Ask students to draw conclusions about energy transfer out of the reaction and bond strengths.

Follow up by asking, *Is our answer different depending on which carbon-based fuel is being burned--gasoline, diesel, or something else?* Listen for these ideas:

- Sort of; they are different reactions and transfer different amounts of energy out.
- Not really, since they are all very similar reactions.

Say, *We have figured out a lot of the pieces to help us explain how carbon-based fuels release energy, like we thought at the end of the last lesson. This is probably a good time to pause and put all of those pieces together.*

2 · DEVELOP A GOTTA-HAVE-IT CHECKLIST

16 min

MATERIALS: 3x3 sticky notes, markers, Gotta-Have-It Checklist poster, chart paper, chart paper markers

Develop a Gotta-Have-It Checklist individually. Say, *Many of you mentioned that the reactions inside the piston are at a larger scale than the ones we have been modeling with the simulation and marbles. Let's think about what we would need to do to scale up this model.* ✱ Display **slide C** and talk through the prompts while distributing sticky notes and markers to students. Have students individually write down components, relationships or interactions, and mechanisms they think we would need to create a scaled-up model of what is happening to gasoline inside the piston.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Organize model ideas on chart paper. Display **slide D.** Read through the directions on the slide and then ask if students have any clarifying questions. Have students post potential model ideas on a piece of chart paper, in silence. Once all sticky notes are added, have the class sort their sticky notes into categories of components, relationships or interactions, and mechanisms. Group similar ideas together within each category. ✱

Directions might sound like this: *Which ideas go together? As long as you do not talk, feel free to move any sticky note to any place. You can move yours and those of your classmates. Do not be offended if someone moves yours to a place that you think it does not belong; just move it to where you think it does belong, and remember to stay silent.*

Develop a class consensus Gotta-Have-It Checklist. Display **slide E.** Use students' model ideas on the chart paper and the prompts on the slide to help guide this discussion. Record agreed-upon ideas on the prepared Gotta-Have-It Checklist poster.

KEY IDEAS

Purpose of this discussion: The goal of categorizing ideas on the Gotta-Have-It Checklist is to help students organize their thinking going into modeling and ensure that the most important pieces have been identified within the class. It is not important in this context that students accurately categorize an idea as a component, interaction, or mechanism.

Listen for these ideas and ensure they are identified. Use these questions to help students identify key pieces that should be included in the consensus Gotta-Have-It Checklist:

- To get "bonds": *I notice we have gasoline, carbon dioxide, oxygen, and water molecules listed as components, but we do not have any relationships between how those atoms are connected. What could we add to explain those connections?*
- To get "bonds breaking and forming": *We have the molecules in the reactants and products listed, but how do we get from the gasoline and oxygen to the carbon dioxide and water? What has to happen?*
- To get "energy transfers and net energy changes": *We have done a great job at looking at this reaction through the matter lens (or refer to the M-E-F triangle), but what if we look at this through the crosscutting concept of energy? What would we want to add to our model ideas using our energy lens?*
- To get "energy in the field and KE": *Where is the energy going to or coming from as bonds are breaking and reforming?*
- To get "system boundaries": *Where exactly do we want to follow the energy transfers to and from? What are the specific parts we do and do not care about? How are we defining our system?*
- To elicit evidence: *When/how did we figure that out?*

A sample class consensus Gotta-Have-It Checklist is shown. Keep this poster visible as students first individually develop and then work in pairs to complete their models.

Components	Relationships or Interactions
Spark or compression Reactant molecules (fuel & O_2) Broken-apart/ dissociated atoms Product molecules (H_2O & CO_2) Electrostatic fields System boundaries Kinetic energy, or speed, of molecules Surrounding particles	Electrostatic field between each pair of atoms Energy transfer into system from spark or compression Energy transfer out of system to surroundings Energy transfers into and out of fields Molecules speed up and slow down (kinetic energy changes) Relative bond strength
Mechanisms	
Energy in fields changes as position changes due to electrostatic forces Explains why bonds break and reform in different ways (bond strength differences)	

If students would benefit from working with a partner to develop their lists, that is okay. The transition to individually having students develop these lists is to increase the level of sophistication we are asking students to engage with the practice. You can also provide support to students by encouraging them to consider *different pieces of evidence* to explain *relationships between components of the system*. (SEP: 2.3)

✱ ATTENDING TO EQUITY

Universal Design for Learning: Color-coding sticky notes by category related to the system (component, interaction, or mechanism) is not necessarily useful here. Having to categorize ideas before writing them down may increase students' cognitive load by conflating symbols and comprehension. This additional step would not support students' engagement with *representation*. By having students work silently together to organize the sticky notes after they have been added to the chart paper, additional options for students to use perception are provided, which in turn supports their engagement with *representation*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use evidence to propose possible components and relationships that should be included in a model. (SEP: 2.3)
- Students include changes in kinetic energy by identifying energy flows within, into, and out of electric fields and a defined system. (DCI: PS1.B.1; CCC: 5.2)

What to do: Although students do not need to accurately categorize ideas as a component, relationship/interaction, or mechanism, it is important that the full range of ideas is on the board. If the class is missing a group of ideas, it may help to refer back to students' Progress Trackers or the lesson activities to help trigger the ideas as important pieces of the understanding we have built. If a particular idea or set of ideas is missing, direct students to the lesson in their Progress Trackers or the activity that helped develop the idea(s), and then ask again if students would like to add anything more to the Gotta-Have-It Checklist.

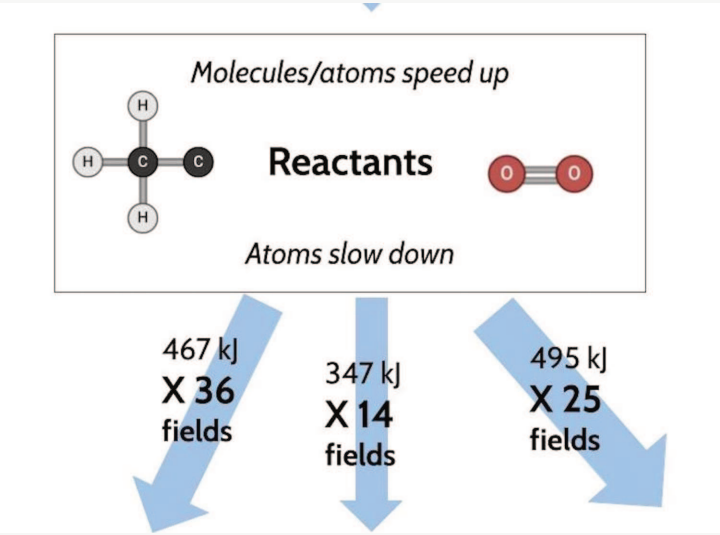
Building toward 8.A.1 Develop a model based on evidence to illustrate energy transfer into or out of a chemical reaction system depending on energy transfer into and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)

3 · MODEL WITH A PARTNER

8 min

MATERIALS: whiteboard, dry-erase markers, Gotta-Have-It Checklist poster

Develop models in pairs. Display **slide F**. Help students get started by drawing the substances involved in the reaction. Highlight to students how you can represent gasoline by showing just the end of the molecule (C-H bonds and one C-C bond), then count the number of bonds broken when you show energy transferring into fields between atoms.



Give partners time to finish their models using the whiteboards. This will make it easier to share models while building a class consensus model at the end of day 1.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use evidence to propose possible components and relationships that should be included in a model. (SEP: 2.3)
- Students include changes in kinetic energy by identifying energy flows within, into, and out of electric fields and a defined system. (DCI: PS1.B.1; CCC: 5.2)
- Students represent electric fields, stable molecules, separated atoms, and changes in kinetic energy. (DCI: PS1.A.4)

What to do: If pairs do not have all of these ideas fully represented, that is okay. Partners will meet with another pair to compare and revise their models. Look for models that have ideas that are represented differently or more completely than others and raise these models up as points of discussion when constructing the class consensus model at the end of day 1. If students' models are missing:

- *changes in energy*: push them to think about specific bond strengths and the role of energy in breaking and forming them.
- *electric fields*: push them to think about where energy is stored when bonds break.
- *system boundaries*: push them to consider which parts of the fuel combustion reaction we are interested in specifically.

Building toward 8.A.2 Develop a model based on evidence to illustrate energy transfer into or out of a chemical reaction system depending on energy transfer into and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)

4 · SHARE PARTNER MODELS

3 min

MATERIALS: whiteboard models, dry-erase markers

Compare models with another pair. Display **slide G**. Have each pair meet with another pair and exchange models. Tell students to focus on differences in how the other pair represented the same ideas. Students will not share out after this discussion. The differences they notice will be helpful during the class consensus model development.

5 · BUILD A CLASS CONSENSUS MODEL

14 min

MATERIALS: whiteboard models, Gotta-Have-It Checklist poster, chart paper, chart paper markers

Model carbon-based fuel combustion. Display **slide H** and gather students in a Scientists Circle. Use the prompts on the slide to help guide the development of a class consensus model. As students suggest different components, interactions, and mechanisms, check for consensus before adding them to the model.

KEY IDEAS

Purpose of this discussion: Build a class consensus model that shows how burning a carbon-based fuel provides energy to make a piston move.

Listen for these ideas:
What components are we defining as parts of the system?

- everything but the surrounding particles and the spark or compression

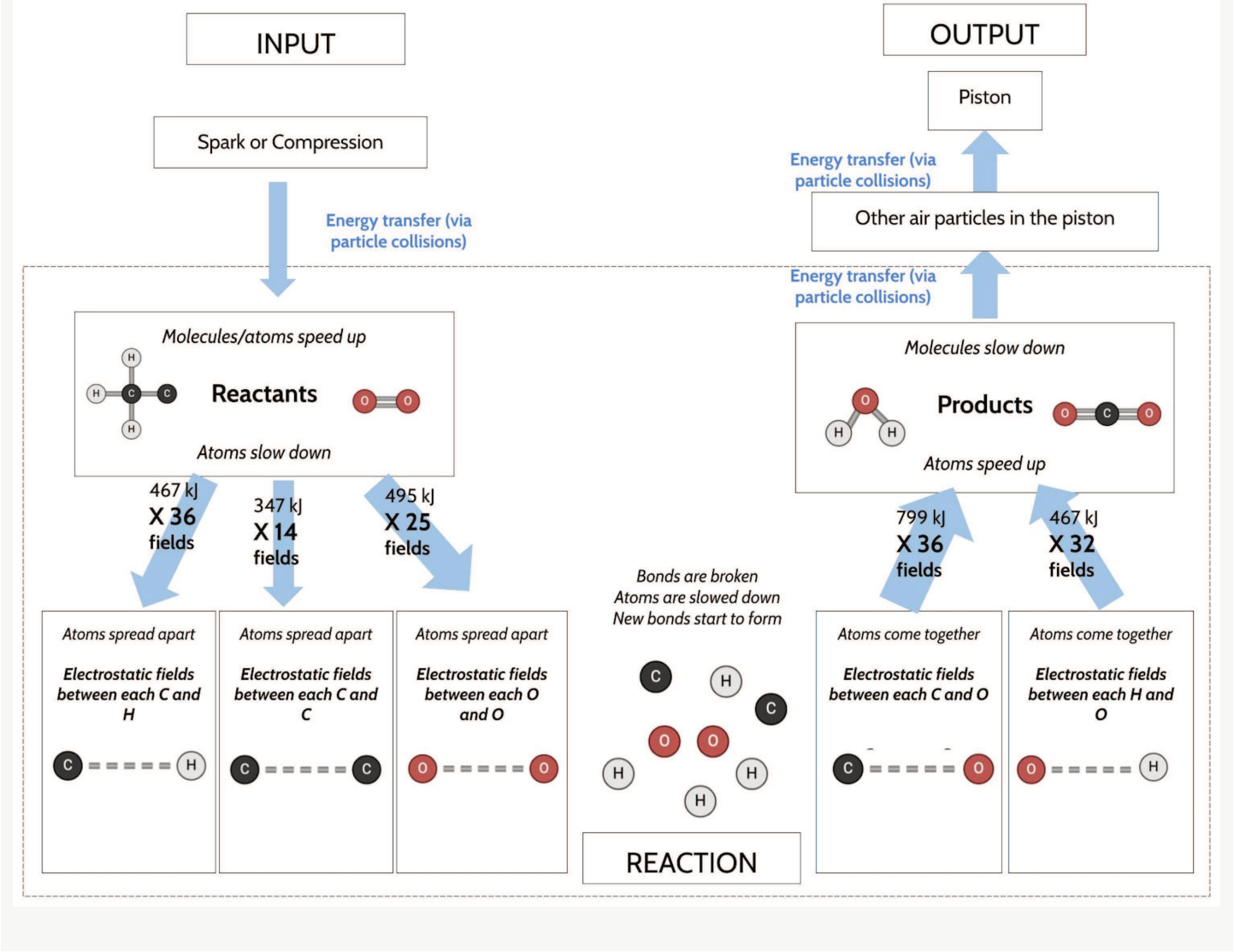
How should we represent the interactions?

- arrows to represent energy flows
- energy transferring from broken bonds to fields (O=O arrow bigger than C-H and C-C arrows)
- energy transferring from fields to formed bonds (C=O arrow bigger than H-O arrow)
- some energy transferring in from spark or compression (thin arrow)
- a lot of energy transferring out of system to surroundings (thick arrow)
- description of molecules speeding up and slowing down or changing in kinetic energy

How should we represent the mechanisms?

- Describe how the energy in fields changes as the forces change.
- Note that new bonds form because they are stronger/more stable.

A sample class consensus model is shown below.


INPUT
Spark or Compression
Energy transfer (via particle collisions)
Molecules/atoms speed up
Reactants
Atoms slow down
467 kJ
X 36
fields
347 kJ
X 14
fields
495 kJ
X 25
fields
Atoms spread apart
Electrostatic fields between each C and H
Atoms spread apart
Electrostatic fields between each C and C
Atoms spread apart
Electrostatic fields between each O and O
Bonds are broken
Atoms are slowed down
New bonds start to form
REACTION
OUTPUT
Piston
Energy transfer (via particle collisions)
Other air particles in the piston
Energy transfer (via particle collisions)
Molecules slow down
Products
Atoms speed up
799 kJ
X 36
fields
467 kJ
X 32
fields
Atoms come together
Electrostatic fields between each C and O
Atoms come together
Electrostatic fields between each H and O

End of day 1

6 · EXPLAIN DIFFERENT FUELS

6 min

MATERIALS: science notebook, class consensus model from day 1

Navigate into the class. Remind students that they ended the prior class by developing a model for energy transfer in gasoline combustion.

Explain different fuels. Return to the class consensus model. Display **slide I** and say, *We have this model to help explain why combustion of gasoline releases energy. Does this model apply to every fuel?* Accept all responses. Listen for students to suggest:

- Yes, but it's not always the same amount of energy.
- It depends on the specific fuel.
- It depends on what the fuel is made of.

Use these responses to suggest that the class try to apply the consensus model to a variety of fuels.✱ Instruct students to choose a fuel and apply what they have learned about bonds, energy transfer, and conservation to explain that particular fuel.

✱ SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Circulate as students are drafting their explanations. Encourage them to use evidence from the class consensus model as well as the investigations and simulations in Lessons 4-7. While they do not need to fully calculate changes in total bond energy, they should cite numbers of bonds and bond energies as evidence to support their thinking.

7 · MAKE COMPARISONS ACROSS FUELS

8 min

MATERIALS: science notebook, class consensus model from day 1

Compare fuels in a small group. Have students get into groups of four to discuss the prompts on **slide J**.

Compare fuels as a class. After two to three minutes, call students together to discuss the prompts on **slide K** as a class.

Suggested prompt	Sample student response
Is anything the same for all fuels and all explanations?	All carbon-based fuels burn and need energy to start. All fuels have the same basic inputs and outputs. All fuels need oxygen and produce carbon dioxide.
Is anything unique to each fuel?	Some fuels have oxygen in them. The fuels are different in the numbers of carbons, hydrogens, and oxygens.

Say, *We know that all of these carbon-based fuels produce carbon dioxide, but do you think they all produce the same amount? How could we use similar thinking to what we have been doing to figure that out?* Students may recall from the Fuel Data Cards that the amount of carbon dioxide depends on the fuel, but they may or may not link this to the number of carbon atoms. It is okay if they do not.

8 · CALCULATE CARBON DIOXIDE EMISSIONS

17 min

MATERIALS: science notebook, *Calculating Carbon Emissions*

Motivate calculating carbon emissions across vehicles. Say, *As we think about carbon dioxide emissions, it might help to think beyond just the*

✱ SUPPORTING STUDENTS IN

fuels themselves. We know from the vehicles around us that they are not all the same. Discuss the prompts on **slide L** as a class.✱

Suggested prompts	Sample student responses	Follow-up questions
What is different about a small car versus a pickup truck versus a semi truck?	Smaller vehicles usually have better gas mileage and big vehicles have worse gas mileage. You can tow or carry more stuff with a bigger vehicle.	*How do those differences play out when you fill up the fuel tank?* *What is mileage?*
How do fuel efficiency or gas mileage, vehicle size, and energy output relate to one another?	A larger vehicle needs more energy to make it move. A larger vehicle has to burn more fuel to go a certain distance.	*How would that impact carbon dioxide emissions?*

Calculate carbon dioxide and other emissions. Tell students, *We know that all of these fuels produce carbon dioxide when they combust, and we have seen that different fuels produce different amounts of carbon dioxide, but how do we know how much carbon dioxide a fuel produces?* Display **slide M** and distribute *Calculating Carbon Emissions*. Give students about 15 minutes to complete the handout in pairs.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use mole ratios from the balanced chemical equation to help them determine the carbon dioxide produced by the combustion of fuel. (SEP: 4.1; CCC: 5.1)

What to do: If students are struggling to set up the calculations, help them talk through the starting unit, final unit, and conversion factors needed for a particular calculation. Direct students to the stoichiometric ratios in the balanced chemical equations they wrote for the first question of *Calculating Carbon Emissions*. If students need additional support, provide conversion factors or units to support their sensemaking. Sample calculations are available in *Calculating Carbon Emissions Key*. Students will determine the amounts of CO_2 and SO_2 produced by various fuels and vehicles. If students struggle or may not finish in time, focus them on those calculations, as they will need that information for the class discussion in the next step.

Building toward 8.B.1 Use mathematical models to show that matter is conserved during fuel combustion and to support claims about fuel efficiency in vehicles and the impacts of carbon-based fuel use. (SEP: 4.1; DCI: ESS3.B.1; CCC: 5.1)

DEVELOPING AND USING ENERGY AND MATTER

This lesson depends on students identifying both matter and energy flows in the combustion engine. Matter and energy are important lenses for chemistry, but this unit is the first to weave together the output energy of a combustion reaction with the tracing of molecular transformations. Encourage students to use both matter and energy in their reasoning.

9 · DEBRIEF CALCULATIONS AND UPDATE PROGRESS TRACKERS

9 min

MATERIALS: science notebook, *Calculating Carbon Emissions*

Debrief calculations. Once students have had time to complete *Calculating Carbon Emissions*, call the class back together to report out. Start by polling the class to get a sense of which students chose which fuels; this will help you to ensure that information about each fuel is shared. You can also ask for volunteers based on fuel type during the discussion, using the prompts on **slide N**.

Suggested prompts	Sample student responses	Follow-up questions
What seems to be the relationship between fuel type and carbon dioxide emissions?	Fuels with more carbon atoms produce more carbon dioxide emissions. It's worse with bigger vehicles.	*How do you know that from your calculations?*
How does this affect your thinking about our current (and future) fuel and transportation use?	These fuels all produce a lot of CO_2 and also other pollution. We need to use less of all of these fuels. We need to think about other types of fuels. Bigger vehicles use more fuel and release more CO_2, so if we could replace some of them that would help.	*What can we do about this?*
How would people around the world be affected if everyone was using carbon-based fuels to get around? Think about our other studies of climate change.	That is A LOT of CO_2 and pollution. Climate change would be worse than it already is or will keep getting worse. More polar ice melt and sea-level rise. People would have to move. More ocean acidification. Higher temperatures might be dangerous for people and might make it harder to grow food, leading to famine.	*What might the impacts be on human migration if average temperatures continue to increase? Who would be affected and how?* *What might the impacts be on the size of the human population if average temperatures continue to increase? Who would be affected and how?*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students cite calculations as evidence that some fuels release more CO_2 than others. (SEP: 4.1; CCC: 5.1)
- Students relate the use of carbon-based fuels to climate change as an impact on human populations. (DCI: ESS3.B.1)

What to do: Encourage students to consider the implications of the math they just did; tell them the point of these calculations is to help students grasp the impacts of carbon-based fuels on people around the world. Remind students of investigations from other units where they learned about specific impacts of climate change and help students connect those ideas to this unit and the calculations they just completed.

Building toward 8.B.2 Use mathematical models to show that matter is conserved during fuel combustion and to support claims about fuel efficiency in vehicles and the impacts of carbon-based fuel use. (SEP: 4.1; DCI: ESS3.B.1; CCC: 5.1)

Update Progress Trackers. Suggest that we have identified a lot of important ideas and it might be useful to capture them in our Progress Trackers. Display **slide O** and give students a few minutes to update their Progress Trackers. A sample entry is shown and can also be found in *Progress Tracker Key*.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	**Engineering implications** Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
CO_2 production rates vary by fuel type and by size of vehicle. The math showed that fuels with more carbons produce more CO_2, and the mass of CO_2 can be greater than the mass of the fuel! Larger vehicles like trucks or semis that run on diesel or biodiesel will produce the most CO_2.	*We need to shrink the size of our vehicles to optimize fuel efficiency.* *We need to drive less.* *We need to produce and use fuels that produce less CO_2.*	Avoid: *Low-efficiency vehicles with tiny cargo loads (big SUVs or trucks with few people in them, school buses running routes with only 6 kids, etc.)* Shift: *Walk and bike when we can, shift to fuels with less carbon.* Improve: *Automotive design so that vehicles are more efficient and optimized for their type of fuel, or optimized for lower carbon dioxide emission fuels.*

10 · IDENTIFY QUESTIONS WE HAVE ANSWERED

5 min

MATERIALS: science notebook, *Our DQB Questions*

Navigate. Say, *Wow, we have figured out so many different pieces to help answer many of the questions on our Driving Question Board.* Distribute *Our DQB Questions* and display **slide P**. Read through the directions on the handout and ask students if they have any clarifying questions. Tell them to focus on marking up their handouts individually in the last few minutes of class and that they will have an opportunity to hear from each other next class.

ADDITIONAL GUIDANCE Ensure that students develop an answer for at least one DQB question. This serves as a review for the upcoming assessment and will help during the Consensus Discussion in the next lesson step.

Provide students an opportunity to record any new questions they may have.

End of day 2

11 · SHARE DQB QUESTIONS WE CAN ANSWER

8 min

MATERIALS: science notebook, *Our DQB Questions*, sticky notes, colored marker, DQB

Share DQB evaluation with a partner. Display **slide Q**. Give students three minutes to compare handouts and choose questions to answer. Provide students an opportunity to add any new questions they may have to the DQB. Students may be wondering:

- What other options for fuels exist other than carbon-based fuels?
- How do we know what fuels to use that release less CO_2?
- Can we design more efficient cars that burn less fuel?
- What other transportation options exist other than driving individual cars?

Mark questions on the classroom DQB. Display **slide R**. Distribute a marker to each student. Read through the directions on the slide and ask if students have any clarifying questions. Point out that making progress on a question does not necessarily mean that we can fully answer the question. ✱

ADDITIONAL GUIDANCE

If your DQB is relatively small and difficult to read by more than a couple of students at a time, you may ask students to line up with their notebooks and file by the DQB. Then, they can look at their notebooks while they wait.

If students have been working on a digital version of the DQB, give all students two minutes to analyze the handout in their notebooks and then two more minutes to analyze the class DQB.

Reflect on answered questions in a Scientists Circle. Display **slide S** and discuss the prompts in the Scientists Circle.

KEY IDEAS

Purpose of this discussion: To come to consensus about the questions we think we have answered, have left unanswered, or have more questions about. To prepare for the upcoming assessment by discussing the answers to key questions.✱

Encourage as many students as possible to contribute to this discussion because you want consensus to represent the whole class, not just a few students. It may be helpful to explicitly tell this to the class at the start of the discussion. Say that you might invite others to share who have not yet contributed to the conversation.

Listen for these ideas:

- Students should be using their student models and other evidence collected during the unit to provide answers to questions on the DQB.
- Students should be working together to identify patterns in the types of questions they answered.
- Students should be able to provide evidence-based answers to questions about the following topics:
  - why some fuels release more CO_2 and energy than others
  - why we use so many carbon-based fuels
  - how fuels make pistons and vehicles move
  - where the CO_2 comes from in fuels
  - what makes fuels like gasoline and diesel different from one another
  - which models are most effective to explain how burning carbon-based fuels provides energy
  - where the energy comes from and goes to during the reaction
- Students should be able to provide some evidence for, but might not be able to put together complete answers to, these questions:
  - How do nuclear reactions or other fuels provide energy for transportation?
  - How can we design other fuels to meet our transportation needs?

✱ ATTENDING TO EQUITY

Revisiting the DQB is important for students to feel as though their questions are valued and recognized. While not all questions will have been addressed, this activity helps students see that they are making progress in answering many of their own questions. By now, questions about gasoline, diesel, other fossil fuels, and biofuels have been addressed in this unit.

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

Do not just tell students the answers. If disagreeing ideas emerge, or students indicate confusion, do not give the correct response. Rather, set up the disagreement by saying, *I hear some of us saying we have answered this, but others saying we have not.* Have students with different positions defend their ideas using evidence. Continue the discussion until the whole class has either come to consensus or agreed to disagree until we gain more information.

Suggested prompt	Sample student response
What did you notice as you looked at the DQB?	We have made progress on some of the questions! Not all of the questions are answered.
Which group(s) of questions have we made the most progress on?	Questions about gasoline, diesel, and other fossil fuels. We have made progress on what happens when a carbon-based fuel burns. We have made a lot of progress on why energy is transferred out of the reaction.
What questions do you have about any of the ideas that have been shared?	Accept all responses. Work through any confusion or partial understandings that students may have.

ALTERNATE ACTIVITY

This DQB check-in may be used as a self-assessment moment for students. Encourage them to reflect on the extent to which they understood the answers to different questions, and felt comfortable engaging in the practices and using the crosscutting concepts to figure them out.

12 · INTRODUCE THE PHENOMENON FOR THE TRANSFER TASK

5 min

MATERIALS: *Cold Pack Scenario* or *Hot Pack Scenario*, instant cold pack, instant hot pack

Consider a new phenomenon. Say, *When we investigated bonds with the rulers, marbles, and simulations, we noticed that sometimes more energy went in and sometimes more energy came out. How might these differences in energy input and output affect temperature?* Listen for responses such as:

- We know that combustion gets hot and the bonds that form are stronger.
- If the bonds that break are stronger, maybe the reaction gets colder?

Display **slide T**. Hold up the instant cold pack. Ask the students the questions on the slide and accept all student responses.

Introduce the scenario. Display **slide U**. Distribute *Cold Pack Scenario* and *Hot Pack Scenario* to students. Be sure to give students the reading that corresponds to the investigation they will complete. Give students time to read the scenario and annotate the text. ✱

ADDITIONAL GUIDANCE

There are two versions of the mid-unit assessment. One is focused on the exothermic reaction in an instant hot pack, the other on the endothermic reaction in an instant cold pack. It is up to you how to use the two assessments: as a pretest and posttest, as a test and re-test opportunity, or as two versions of the mid-unit assessment. If you use them simultaneously as the mid-unit assessment, plan ahead which students will take each version and assign students the corresponding reading and investigation to complete. Alternatively, you can let students choose whether they wish to investigate cold packs or hot packs and give them the reading, investigation materials, and assessment that correspond to their choice.

Discuss the scenarios. Display **slide V**.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: This strategy of providing the assessment scenario ahead of the assessment can be beneficial to emergent multilinguals as well as any other students who might benefit from the cognitive load being reduced when processing the scenario. In addition, the explicit discussion of prefixes in "exothermic" and "endothermic" supports learners in contrasting these different reaction types.

Allow students to share any words they may not know or portions of *Cold Pack Scenario* or *Hot Pack Scenario* they may need help processing. This will support students later as they complete the mid-unit assessment.

Suggested prompt	Sample student response
Why are chemically activated cold or hot packs helpful to have on hand?	Sometimes you don't have ice readily available, like outside on a soccer field or baseball diamond. When someone gets injured, it's good to have these cold packs because you can keep them in a bag at room temperature. The hot packs can be helpful if you're outside in the cold, or if you need a heating pad for an injury.
What did the reading claim were options for substances in a cold pack or hot pack?	Urea and water for cold packs. Calcium chloride or magnesium sulfate for hot packs.

Discuss energy transfers in the cold pack and hot pack. Display **slide W.** Acknowledge that what is happening in the hot and cold packs is not quite the same as bonds breaking and forming like we have seen in combustion reactions, but point out that there are parallels.

Suggested prompt	Sample student response
What happens in the hot and cold packs that is similar to bonds breaking? What does the text call the energy associated with that?	Ions dissociate, which is like breaking bonds. Energy has to go in to separate the ions. This is called the lattice energy. Ionic bonds break, but new bonds don't exactly form, so that's different.
What happens in the hot and cold packs that is similar to bonds forming? What does the text call the energy associated with that?	The water molecules pull on the ions. Energy is released when ions are hydrated or surrounded by water. This is called the energy of hydration.
What would make this process exothermic or endothermic?	If more energy is released than goes in, it will be exothermic. If more energy goes in than is released, it will be endothermic.

Summarize the scenarios. Ask students which pack, the cold pack or hot pack, has a larger energy output than energy input. Listen for students to say the hot pack, but it is okay if students are unsure. Tell students that you have the substances from hot packs and cold packs on hand so that the class can investigate them.

13 · CONDUCT COLD/HOT PACK INVESTIGATION

8 min

MATERIALS: Cold/Hot Pack Investigation

ADDITIONAL GUIDANCE Prepare investigation materials ahead of time and consider having stations already set up for groups. This will help decrease the amount of time students will need to complete the investigations.

Review safety guidelines. Give students a moment to read and ask questions about the safety guidelines on **slide X.**✱

✱ ATTENDING TO EQUITY

Universal Design for Learning: Engagement. Students will investigate a reaction that powers hot packs or cold packs. By observing

SAFETY PRECAUTIONS



Highlight guidelines around wearing sanitized indirectly vented chemical splash goggles, non-latex aprons, and nitrile gloves; washing hands; and not tasting substances in the lab. Review the SDS before using potassium chloride and calcium chloride, and make students aware of all hazards. Secure loose clothing, remove loose jewelry, wear close-toed shoes, and tie back long hair. Remind students to use caution in working with glassware--broken glass creates sharps which can cut skin. Make sure students are instructed on how to appropriately dispose of or store salt solutions.

Explain and conduct the Cold and Hot Pack Investigations. Have students form groups of 5 to conduct the investigation. Distribute beakers with 25 mL of distilled water to each group. Alternatively, you can place the water in a central location and have students measure the water themselves. Distribute the calcium chloride (hot pack) and potassium chloride (cold pack) samples, making sure students get the sample that corresponds to the scenario they read. Say, *Let's see how well these instant hot and cold packs work. Notice that you have beakers and powders instead of the actual hot and cold packs. You will be simulating the reaction that happens inside a hot or cold pack when the barrier is broken.* Walk students through the procedure on **slide Y**. Ask if students have any clarifying questions.

Vary the kinetic energy that goes into the solutions. The instructions tell groups to mix the solution but NOT to stir it immediately. This will motivate differences in the initial input of kinetic energy to break bonds and start a reaction. After a few moments of not stirring and watching the temperature, students can then stir and watch the temperature change again. Students only need to record the initial and final temperatures of the reaction in their science notebooks. Sample data may be found in *Sample Data*.

this reaction's dramatic temperature change with their senses, students will have deeper motivation for figuring out the reaction's components in the assessment task.

14 · COMPLETE MID-UNIT ASSESSMENT

24 min

MATERIALS: *Cold Pack Assessment* or *Hot Pack Assessment*, *Cold Pack Scenario* or *Hot Pack Scenario*, science notebook

Prepare students to take the individual mid-unit assessment. Display **slide Z**. Distribute *Cold Pack Assessment* and *Hot Pack Assessment*, then give students time to complete the assessment.

ADDITIONAL GUIDANCE

Students should get the version of the assessment that corresponds to their version of the reading and investigation. Students who read about cold packs and investigated potassium chloride should get *Cold Pack Assessment*, and students who read about hot packs and investigated calcium chloride should get *Hot Pack Assessment*.

ALTERNATE ACTIVITY

Extension opportunity: If you wish to assess students' bond energy calculations, you may do so using this assessment. There are three levels to this extension, each increasingly difficult.

1. To assess bond energy calculations alone: Ask students to estimate how much energy would be transferred into or out of the system when a mole of their salt interacts with water. (29 kJ/mol for KCl, -120 kJ/mol for $CaCl_2$)
2. To also assess use of molar mass from *Oysters Unit*: Ask students to estimate how much energy should have been transferred into or out of the system given 5 g of salt. (1.95 kJ for KCl, -5.41 kJ for $CaCl_2$)
3. To assess ideas throughout the course: Ask students to do the above and use ideas from *Polar Ice Unit* to calculate the temperature change that should have occurred in the water, given ideal conditions. The specific heat of water is 4.18 kJ/(g * °C). (18.7 °C decrease for KCl, 51.8°C increase for $CaCl_2$)

Note that students' estimates for (3) will reflect significantly greater temperature changes than observed. This is because energy transfers to the surrounding air, as well as the water, in this investigation.

ASSESSMENT OPPORTUNITY	**What to look/listen for in the moment:** See *Cold Pack Key/Rubric* and *Hot Pack Key/Rubric* for guidance. **What to do:** It is recommended that you let students complete this summative assessment using their science notebooks and *Progress Tracker* if they need extra support. Since this is a summative assessment, you could give students another opportunity to retake the assessment to demonstrate mastery or spend time reviewing what the class should have figured out to support students in their mastery of these concepts. **Building toward 8.A.3** Develop a model based on evidence to illustrate energy transfer into or out of a chemical reaction system depending on energy transfer into and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)

Navigate to the next lesson. Display **slide AA**. Ask, *Which groups of DQB questions do we still need to make progress on?* Highlight those that focus on fuel sources that are not carbon-based. Let students know that we will work to make progress on those next.

Additional Lesson 8 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. Students synthesize information from the class consensus model, the Cold Pack or Hot Pack Investigation, and *Cold Pack Scenario* or *Hot Pack Scenario* to develop written explanations and models throughout the lesson and on *Cold Pack Assessment* or *Hot Pack Assessment*.
SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	CCSS.MATH.CONTENT.HS.N-Q.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and interpret the scale and the origin in graphs and data displays~~. Students work to quantify and scale up energy transfer and carbon dioxide emissions as a result of the combustion of carbon-based fuels on *Calculating Carbon Emissions*. They use unit conversions to move between grams, moles, and kJ. The teacher then walks through how to move from grams to kilograms of fuel and then convert to kilograms of carbon dioxide.

LESSON 9: Where is the energy coming from (and what are some trade-offs) when we use batteries to power vehicles?

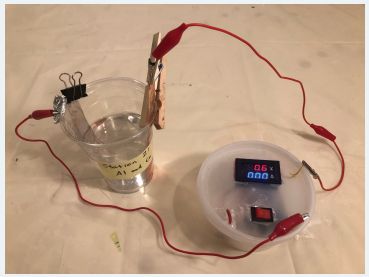
PREVIOUS LESSON

We modeled how carbon-based fuels like gasoline provide energy. We applied our model to different fuels and examined how much carbon dioxide is released when different fuels and vehicles are used. We updated our Progress Tracker. We checked in on our DQB and completed a mid-unit assessment on cold packs or hot packs.

THIS LESSON

INVESTIGATION

2 days



We evaluate arguments about electric vehicles and want to better understand how they work, since improved batteries are a continuing need. We analyze images of the components found inside different batteries. We collect data on the voltages produced by different metal electrodes. We analyze data on the current produced by different electrolytes. We argue for a proposed combination of solutions and metals that would provide the highest energy output rate.

NEXT LESSON

We will examine hydrogen fuel cells and compare them to batteries and engines. We will see how fuel cells produce energy and examine data on hydrogen production. We will use data and molecular models to understand why some gasses are greenhouse gasses. We will revisit our criteria and constraints and update our Progress Trackers.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

9.A Compare and evaluate arguments about a new transportation technology (batteries and EVs) to reduce pollution while considering its impact on the transportation system. (SEP: 7.1; DCI: ESS3.C.2; CCC: 2.3)

9.B Use evidence from student investigations and research to propose a battery design that results in the largest energy output based on the types of solutions and metals used in the battery and the matter and force interactions between them. (SEP: 6.5; DCI: PS3.A.4; CCC: 2.2)

WHAT STUDENTS WILL FIGURE OUT

- Batteries and EVs have a lot of benefits but also some drawbacks in the short term relating to the environment and accessibility.
- Differences in the types of solutions and metals used in batteries can affect the energy they can provide.
- Combining metals with a larger difference in electronegativity in a battery can transfer more energy.
- Batteries provide a vehicle energy as electrons move through wires and ions move through solution, transferring energy from fields to particles.

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Return to the DQB and consider which fuels we have not answered questions about yet.	A	*Our DQB Questions*, Driving Question Board
2	23 min		**EVALUATE ARGUMENTS ABOUT ELECTRIC VEHICLES** Gather students in a Scientists Circle to evaluate arguments for and against long-distance electric vehicles (EVs) using evidence.	B-F	*Point: Environmental Impacts*, *Point: Addressing Accessibility*, *Counterpoint: Environmental Impacts*, *Counterpoint: Addressing Accessibility*, Community Agreements
3	14 min		**EXAMINE INTERNAL STRUCTURES OF BATTERIES** Have students turn and talk with a partner to share their personal experiences with batteries. Have students examine *Comparing Different Batteries* and record differences in their science notebooks.	G-L	*Comparing Different Batteries*, *Battery Model*, M-E-F poster, chart paper, chart paper markers
4	5 min		**DEMONSTRATE THE VOLTMETER** Introduce the relationship of rate of energy transfer to voltage and current. Conduct the Voltmeter Demonstration.	M-O	Voltmeter Demonstration
					End of day 1
5	12 min		**COLLECT VOLTAGE DATA ON DIFFERENT METALS IN BATTERIES** Organize students in lab groups to complete the Measuring Electrode Voltages Investigation.	P-R	Measuring Electrode Voltages Investigation
6	7 min		**ANALYZE RESULTS AND DEVELOP AND USE A MODEL** Have students analyze and discuss the results of the investigation. As a class, develop and use a model to explain the results from a forces perspective.	S-U	*Battery Model*, "Batteries" poster, chart paper markers
7	10 min		**CONSIDER ELECTROLYTES IN BATTERIES** Have students share initial ideas about the influence of electrolytes on energy transfer in a battery.	V-Z	*Battery Model*, "Batteries" poster, table salt, cup of water, chart paper markers
8	5 min		**ANALYZE ELECTROLYTE DATA AND REVISE BATTERY MODEL** Have students analyze additional data on ion concentrations for different electrolytes. Revise the "Batteries" poster based on new information.	AA-DD	*Electrolyte Current Data*, *Ion Concentrations* (optional), *Battery Model*, "Batteries" poster, chart paper markers
9	10 min		**DEVELOP BATTERY DESIGN PROPOSAL AND SUMMARIZE FINDINGS** Have students develop a battery design proposal that would provide the highest rate of energy transfer to an electrically powered device.	EE-FF	*Battery Design Proposal*, *Electrolyte Current Data*, Progress Tracker, *Electronic Exit Tickets* from Lesson 5, "Batteries" poster, M-E-F poster
10	1 min		**NAVIGATE** Navigate students to the next lesson.	GG	Fuel Data Cards from Lesson 1 (optional)
					End of day 2

Lesson 9 • Materials List

	per student	per group	per class
Voltmeter Demonstration materials	• sanitized indirectly vented chemical splash goggles		• 1 ammeter/voltmeter • 1 battery (1.5V) • yellow wire with alligator clips • black wire with alligator clips • electrical tape
Measuring Electrode Voltages Investigation materials	• science notebook • *Measuring Voltage Procedure* • sanitized indirectly vented chemical splash goggles • non-latex nitrile gloves • non-latex apron		• 7 voltmeters • 7 clear beakers or plastic cups • 14 electrodes (5 aluminum - 5 copper - 2 zinc - 2 iron) • 3 L stock electrolyte solution (3 L distilled water - 60 g table salt - 45 mL vinegar) • 14 plastic clothespins or binder clips
Lesson materials	• *Our DQB Questions* • *Comparing Different Batteries* • *Battery Model* • science notebook • *Electrolyte Current Data* • *Ion Concentrations* (optional) • *Battery Design Proposal* • Progress Tracker	• *Point: Environmental Impacts* • *Point: Addressing Accessibility* • *Counterpoint: Environmental Impacts* • *Counterpoint: Addressing Accessibility*	• Driving Question Board • Community Agreements • M-E-F poster • chart paper • chart paper markers • "Batteries" poster • table salt • cup of water • *Electronic Exit Tickets* from Lesson 5 • Fuel Data Cards from Lesson 1 (optional)

Materials preparation (30 minutes)

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

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

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

Have the Driving Question Board available on day 1. On day 2, you will need the following Fuel Data Cards from Lesson 1: biodiesel, diesel, gasoline, ethanol, lithium, and other batteries.

On day 1, students will read different arguments related to electric vehicles. Have enough copies of each for ¼ of the class:

- *Point: Environmental Impacts*
- *Point: Addressing Accessibility*
- *Counterpoint: Environmental Impacts*
- *Counterpoint: Addressing Accessibility*

Review *Discussion Mapping Tool* before day 1 to orient yourself with the use of a discussion mapping tool during a Scientists Circle.

Print enough copies of *Comparing Different Batteries* and *Measuring Voltage Procedure* so that each student in your largest class has a copy. Consider laminating or placing in a page protector for repeated use.

Prepare a large piece of chart paper for the "Batteries" poster that you will add to over the course of the lesson.

Have the M-E-F poster visible.

If desired, create a Google Form for students' design proposals for this lesson using the directions found on *Electronic Exit Tickets* from Lesson 5.

Follow these general safety protocols throughout:

- Wear indirectly vented chemical splash goggles, non-latex apron and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Immediately wipe up any spilled water on the floor--this is a slip-and-fall hazard.
- Follow procedures set up by your instructor for disposal of materials.
- Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Prevent the ends of both alligator clips connected to either end of the battery from touching in this activity. This will short circuit the battery and cause it to heat up quickly, which can be a potential fire hazard.
- Keeping the battery connected to wires can cause overheating. Only use for a short time. Disconnect if wires are heating up quickly.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Use caution with working with wires - these are considered sharps and can scratch or cut skin.
- Use caution when working with glassware or plasticware--can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Direct supervision will be required during all aspects of this activity.

Day 1: Voltmeter Demonstration

- **Group size:** Whole class
- **Setup:**
    - Set aside a black wire with alligator clips, a yellow wire with alligator clips, and a 1.5V battery.
    - See *Voltmeter Build Directions* for detailed setup instructions for turning an ammeter you built in *Electrostatics Unit* into a voltmeter/ammeter that you will use in this demonstration. The one you use in the demonstration will be one of the seven that you provide to student groups for the next investigation.
- **Safety:** Prevent the ends of both wires with alligator clips (connected to either end of the battery) from touching at all times. If the ends touch, this will short circuit the battery and cause it to heat up quickly, which can be a potential fire hazard.
- **Disposal:** The electrolyte solution may be disposed of in the sink.
- **Storage:** All materials may be reused.

Day 2: Measuring Electrode Voltages Investigation

- **Group size:** 5 students
- **Setup:**
    - See *Voltmeter Build Directions* for detailed setup instructions for turning the 7 ammeters you built in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* into 7 voltmeters.
    - See *Electrode Station Setup* for how to set up and test each of the stations.
- **Notes for during the lab:** Monitor stations to make sure the bottoms of the electrodes at each station do not touch, as this will yield a voltage of 0. Separate them if they are touching.
- **Safety:** Students should wear splash goggles during this lab and wash their hands afterward.
- **Disposal:** The electrolyte solution may be disposed of in the sink.
- **Storage:** Many of the metal electrodes will oxidize and/or build up deposits from reacting with electrolytes in the solution. Both processes will degrade their performance for future labs. To help prevent this, do the following:
    - Rinse the metals with distilled water after use and thoroughly dry them to help reduce the amount of corrosion they undergo.
    - Apply a light sanding or scrub the metals with steel wool to help remove corrosion.
    - Apply a thin layer of oil (olive or vegetable) to the surface of the iron to help prevent rusting.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS3.C.2 Human Impacts on Earth Systems:** Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
- **PS3.A.4 Definitions of Energy:** These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). ~~This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.~~

Crossout explanation: Students were introduced to radiation in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and considered it at a high level again in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. Students will not build the idea that radiation involves fields moving across space until the Physics unit *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*.

DCI: ESS3.C.2 was last developed in Lesson 1 as students were introduced to the various types of fuels and technologies that produce less pollution and waste.

This lesson also supports student re-use of a disciplinary core idea developed in *Electrostatics Unit*:

- **PS1.A.3 Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

Early in the lesson, students evaluate arguments about the relative merits of electric vehicles, often related to their environmental impacts (SEP: 7.1; DCI: ESS3.C.2). Students recognize that electric vehicle technology can be further developed to reduce some of its negative impacts (CCC: 2.3). They draw on prior experiences evaluating arguments in *Space Survival Unit* and *Oysters Unit*. They have previously thought explicitly about environmental degradation in those units, as well as in Lesson 1 of this unit, and also considered people's ability to design systems to certain effects in *Oysters Unit*.

Students examine diagrams of different batteries and begin to develop a model to account for energy transfer in a battery. They work in small groups to gather investigative evidence around the impact that different combinations of metals have on voltage (energy) output in a battery (CCC: 2.2). Students then consider differences in the electrolytes found in the battery solutions. They use investigative and electrolyte data to propose a battery design that would result in the greatest energy output (SEP: 6.5; DCI: PS3.A.4). Students leverage prior experiences with design from *Oysters Unit*, particle-level energy from *Electrostatics Unit*, and a focus on smaller-scale mechanisms in Lessons 3 and 6. In Lesson Set 3, students will expand their arguments and designs from the single-technology level to the system level.

Where We Are NOT Going

Students do not fully explain the differences in the properties of the metals used as cathodes or anodes in the battery. While the anode and cathode are important parts of the battery, students do not need to memorize the names of both of these, nor which one the electrons flow to. They simply need to know that these are common structures in batteries and that electrons flow from one to the other.

Students may see some physical differences on the metals that make up the anode and cathode after measuring the voltages of different combinations of metals, which may indicate that there is a difference in how two metals are interacting to release energy. While changes in electrode color or mechanical properties could be evidence of a chemical reaction, thinking about what is happening in a battery as a chemical reaction is not the focus of this lesson, nor is determining that new substances (products) are forming in this process.

This lesson does not seek to fully explain redox reactions or break the system down into half-cells, as these ideas are outside the bounds of the NGSS. This lesson also does not go into balancing reduction-oxidation reactions or require that students identify oxidized or reduced species.

The mathematical relationship *current × voltage = rate of energy transfer* is provided on **slide N** to support the idea that both current and voltage contribute to the rate of energy transfer out of the battery. This motivates the type of data students will collect (voltage) and analyze (current) for combinations of substances that would be best to use inside a battery. The rate of energy transfer is not named as power. Voltage and current are used as proxies for energy in this lesson because the former is listed on batteries, and the latter is familiar from *Electrostatics Unit*. It is not important that students distinguish between these measures.

This lesson only considers how the type of electrolyte and concentration of ions would affect this maximum current. Internal resistance and other factors in a battery are not discussed in this lesson. Though the teacher refers to the parts of the device students are using that takes measurements of current and voltage as an ammeter and voltmeter respectively, this distinction is not an important one for students to keep track of.

LEARNING PLAN for LESSON 9

1 · NAVIGATE

3 min

MATERIALS: *Our DQB Questions*, Driving Question Board

Return to the DQB. Display **slide A.** Say, *The model we developed helps us explain how carbon-based fuels are burned to produce energy for transportation. But what questions do we have about the other fuels? Let's see which fuels we had questions about on our Driving Question Board.*

Give students a moment to reflect on *Our DQB Questions* and then discuss the prompts as a class.

Suggested prompt	Sample student response
What do we want to know more about?	How electric vehicles (EVs) and batteries can make our transportation systems better. Why EVs are not used more often in personal transportation.
Of the non-carbon-based fuels mentioned on the DQB, which do we have the most firsthand experience with?	Batteries!

Elicit students' prior knowledge about using batteries in vehicles. Accept all responses. Leverage these ideas to point out that electric vehicles have become more common in recent years, and different people have different perspectives about them.

2 · EVALUATE ARGUMENTS ABOUT ELECTRIC VEHICLES

23 min

MATERIALS: *Point: Environmental Impacts*, *Point: Addressing Accessibility*, *Counterpoint: Environmental Impacts*, *Counterpoint: Addressing Accessibility*, Community Agreements

Introduce the arguments for/against EVs. Display **slide B**. Share four different arguments related to EVs:

- *Point: Environmental Impacts*
- *Point: Addressing Accessibility*
- *Counterpoint: Environmental Impacts*
- *Counterpoint: Addressing Accessibility*

Assign students one of the four handouts to evaluate, as they will hear from other students with different arguments during the following Scientists Circle. Ensure even distribution, but consider assigning students with the strongest opinions a reading that will introduce arguments counter to their own thinking.

ADDITIONAL GUIDANCE

Students will go directly into a class discussion after this independent activity. Since this is the last unit in the course, it is anticipated that students will feel comfortable sharing ideas from the reading without checking in with classmates who read either the same or a different argument. Provide additional time to debrief readings in small groups if you feel it is necessary.

Introduce the discussion mapping tool. Display **slide C**. Have students meet in a Scientists Circle and explain that we will be participating in a Building Understandings Discussion to share the evidence we gathered.✱ Say, *We are going to use a mapping tool to track our discussion. This will help us think about how we can all work together when we are discussing new ideas to move our thinking forward.* The purpose of this particular discussion is to have the class evaluate all four arguments to identify the important engineering implications of using electric vehicles in place of vehicles that use carbon-based fuels. Ask students which two focal Community Agreements they think will be important to balance for this discussion. Students will likely say *respect* and *moving our thinking forward*. If the class suggests other Community Agreements and is in agreement on why they are important, adopt those as the focus for this discussion instead.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful kind of discussion following an investigation or reading because the purpose is to focus students on drawing conclusions (or in this case, evaluating arguments) based on evidence. Your role during the discussion is to invite students to share conclusions and claims and push them to support them with evidence. Students can disagree with each other and the class does not need to reach consensus on all ideas shared. Areas of disagreement can motivate future investigations. Helpful prompts during these types of discussions include:

- What can we conclude?
- How did you arrive at that conclusion?
- What is your evidence?

KEY IDEAS

Purpose of the discussion: To help students recognize the promise of and problems with electric vehicles, and recognize that some of the concerns can be addressed through technological innovation. This will motivate students to figure out how batteries work and engage in a short engineering design task.

Listen for students to evaluate the argument using key ideas from the class, the argument itself, and ethical considerations:

- Burning fossil fuels releases carbon dioxide. Producing and driving electric vehicles releases some carbon dioxide depending on the electricity source, though less than for gas-powered vehicles.
- The whole life cycle of a vehicle and the fuel it uses must be considered when evaluating it.
- Trade-offs and constraints around cost and accessibility or usability of EVs in different environments must be considered, although life cycle cost tends to be lower for EVs, and other issues can be addressed through government support and technological improvements.
- EVs bring ethical concerns around sourcing of materials, but gas-powered vehicles bring their own environmental, health, and safety concerns as well, even without considering carbon dioxide emissions.

ADDITIONAL GUIDANCE

Discussion Mapping Tool gives students a visual representation of the conversation patterns happening within the class. Use lines to track how the discussion moves between speakers, including yourself. After you track the first several moves, pause the discussion to show students what the map looks like. Now that students have used this discussion mapping tool a few times over the course of the year, you can also ask for a student volunteer who has not yet mapped the discussion to take on that role after you set up the tool. This can be a way to involve a student who is less comfortable speaking publicly. Now that students have used the tool a few times, feel free to include the codes that mark different types of contributions, as seen in *Discussion Mapping Tool*.✱

Discuss evidence and arguments relating to EVs in the Scientists Circle. Display **slide D**. Ask students to start by sharing the arguments they were assigned on their handouts and any evidence they found to support or refute their arguments. Remind students to share and discuss each argument and evidence from all four handouts. After framing the questions, take a seat in the circle as a co-participant rather than as a facilitator. Allow the discussion to center around the shared pieces of evidence for at least 10 minutes. If students fixate on one argument, you may need to prompt students who collected evidence from other handouts to allow the conversation to touch on all arguments.

- Does any group have evidence to support Student A's argument?
- What data or information do we have that challenges Student B's argument?

✱ ATTENDING TO EQUITY

Building classroom culture: This is an important opportunity to emphasize that each individual has contributions to make to their community of learners. It is through differences in thinking that the class will grow their knowledge together. Throughout this unit, students will be asked to be open to sharing knowledge products that depict their current thinking and to be open to learning from classmates who share their knowledge too.

	Supports argument	Counters argument
Obtaining the materials needed to make EVs is dangerous and still emits carbon dioxide, leading to human and environmental injustices.	15 tons of CO_2 are released for every ton of lithium mined with one type of mining. Mining for lithium is super water-intensive. Waste generated from mining cobalt can result in decreased crop yields, contaminated food and water, and health issues. There are human-rights violations and violence associated with mining cobalt because it is so valuable and risky. High temperatures are needed to get some of the other key minerals in EVs. These temperatures can cost-effectively be reached only by burning fossil fuels. If the electricity to charge an EV is generated from burning fossil fuels, powering the vehicle will still release CO_2.	Over the life cycle of an EV compared to a gasoline-powered car, way less emissions are released because there are no tailpipe emissions. A lot of electricity is generated from non-fossil fuel sources. Even if the electricity used to charge an EV is generated from fossil fuels, it releases less CO_2 than burning gasoline. Reusing and recycling batteries can make the use/manufacturing of EVs more environmentally friendly.
Owning and charging EVs is not as accessible to people as owning and fueling gasoline-powered vehicles.	Currently, the average upfront cost to purchase an EV is greater than that of purchasing an equivalent gas-powered car. Charging an EV can be difficult based on where high-speed chargers are. EV batteries have fewer components than a typical internal combustion engine, making it simpler and cheaper to maintain than a gas-powered car. EV batteries take longer to charge and do not hold as much charge in cold temperatures, meaning they cannot travel as far.	EVs are dropping in price and are expected to do so continually over the next decade. The cost of maintenance and recharging an EV is already lower than that of a gas-powered car. Refueling a gas vehicle usually costs more per month than recharging an equivalent EV that is being driven the same amount. There are ways to keep batteries operating in cold weather; they do it in Norway.

Take four minutes to have students consider the implications of these pieces of evidence. Depending on the flow of the discussion, you may need to prompt students to do this by displaying **slide E**. Ask, *What does the evidence relating to these arguments say about the future use of batteries instead of carbon-based fuels?* Listen for these ideas:

- Batteries and EVs are not a perfect solution right now.
- Despite some cons of EVs, they are still a solution that can reduce carbon emissions compared to gasoline-powered vehicles.
- We need to do more to improve battery technology to make their manufacturing more environmentally friendly.
- We need to do more to improve battery technology to make them go for longer ranges and to improve the charging technology.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students compare and evaluate arguments for and against electric vehicles using currently accepted explanations (burning fossil fuels releases CO_2), new evidence (life cycle thinking), limitations and constraints (accessibility), and ethical issues (concerns about mining). (SEP: 7.1; DCI: ESS3.C.2)
- Students identify that batteries and EVs can be used to reduce pollution but still have an environmental impact, and that these concerns could be partly addressed by improving batteries. (DCI: ESS3.C.2; CCC: 2.3)

What to do: Use the discussion map to see which students are engaging in the discussion. To bring more voices (and evaluations of different arguments) to the table, it may be useful to pause the discussion midway through and show students the half-completed map. Ensure that students are evaluating the arguments using a wide variety of prior explanations, evidence, and other considerations. Push students to cite their ideas and consider which of the concerns they raise are permanent compared to those that may be addressed through technological innovation or incentive programs. If students struggle in this discussion, it may be useful to have them practice giving and receiving structured peer feedback on this lesson's design proposal, to promote both reasoned evaluation of arguments and classroom community.

Building toward 9.A.1 Compare and evaluate arguments about a new transportation technology (batteries and EVs) to reduce pollution while considering its impact on the transportation system. (SEP: 7.1; DCI: ESS3.C.2; CCC: 2.3)

ALTERNATE ACTIVITY

If students are interested in getting a national picture, encourage them to explore recharging options on this larger scale. Students should come to the same conclusions, but may point out that some areas have better infrastructure to support the use of battery-powered vehicles than others. If students do not bring up these ideas, they will have another opportunity to explore them in Lesson 10.

Motivate a shift to improving batteries. Summarize student ideas and ask students if batteries will always have these same problems. Display **slide F** and leverage suggestions that batteries could be improved to ask, *What could we do during class to try to improve batteries?* Listen for these ideas:

- We could figure out how they work.
- We could try different designs and compare them.

3 · EXAMINE INTERNAL STRUCTURES OF BATTERIES

14 min

MATERIALS: *Comparing Different Batteries*, *Battery Model*, science notebook, M-E-F poster, chart paper, chart paper markers

Motivate M-E-F thinking. Say, *When we were making sense of a carbon-based fuel early in the unit, what concepts or structures did we use to help us understand how they made vehicles move?* Listen for ideas such as:

- We thought a lot about energy and where it came from or went.
- The matter, or stuff, involved in the reaction
- Forces of attraction that led to bonds forming and breaking
- Forces in the engine

Display the M-E-F poster and suggest that we keep thinking about the matter, energy, and forces in a battery so we can figure out how to make one and improve battery technology.

Share personal experiences with batteries. Display **slide G**. Have students turn and talk with a partner about the prompt on the slide. After two minutes, ask for a few volunteers to share.

Suggested prompt	Sample student response
Consider the different batteries you have encountered in your everyday experiences. What makes a battery "good" for any given use?	I can recharge the battery in my cell phone/tablet/laptop, but other batteries can only be used once. You can recycle batteries at special locations. They aren't really safe for the trash. Some of the batteries you physically remove, others stay in the device and get charged back up when it dies. The battery in a car is rechargeable! Batteries have different shapes (AA, AAA, 9V). You have to have the right one. A good battery lasts a long time.

Share initial ideas about the matter inside a battery. Display **slide H.** Discuss the questions on the slide for two minutes as a class.

Suggested prompt	Sample student response
What do we know about the matter inside a battery when it is working well (electricity is flowing)?	There need to be metals in it for electricity to flow. We read about cars that have lithium batteries. Some batteries are "alkaline," which could refer to the elements in them. I've heard of battery acid, but I'm not sure what it's used for.
What about when a battery is not working (electricity is not flowing)?	Dead batteries can sometimes leak a liquid or paste. Some of the batteries I remove will have a paste on them.

Motivate the need to learn more about different types of batteries based on the uncertainty in some of students' initial ideas.

Examine structures of different types of batteries. Display **slide I**. Distribute *Comparing Different Batteries*. Give students four minutes to look at the images and stop and jot similarities and differences between the batteries in their science notebooks.

Share similarities and differences between batteries. Add the title "Batteries" to the chart paper. This will be the "Batteries" poster. Then, use the prompts to lead a discussion.

Suggested prompt	Sample student response
What is similar between the different types of batteries?	They all provide electrical energy to something. They seem to have two different ends. Either a positive and negative or two different colored wires coming out of them. One of the ends in every battery sends electrons out one wire to flow to another wire. They all have two different types of materials at the ends, usually metals or metal oxides. They all have some electrolytes sandwiched between the ends.
What is different between the different types of batteries?	Their shapes are different. The types of metal and materials inside the battery are different. It looks like there is space between the two different ends in the AA and car batteries, but not in the lithium-ion battery. The AA and car batteries contain a liquid solution where the ions travel across. The ions in the lithium-ion battery travel across a plastic separator with electrolytes on it.
What is the matter that makes batteries work?	Electrons. Metals. Something in the middle with ions.

Build a model of a battery. Display **slide J**. Explain that you are going to draw a simplified diagram on the poster to represent the similar parts of battery systems so that we can keep track of what is going on in a battery. Distribute *Battery Model* so that students can add to their model as they develop a fuller understanding of batteries.

Name the metal components. Say, *The two metal ends in the system that you noticed in each battery are called the cathode and the anode.* Update the "Batteries" poster by labeling Metal A as the anode and Metal B as the cathode. Point out that Metal A is different from Metal B in the example batteries we have looked at so far.

Transition to energy. Point out the similarity students mentioned, that all batteries transfer energy in the form of electricity to some kind of device between the cathode and anode. Add a wire connecting Metals A and B, as shown. Also add the following ideas to the poster:

Transfer of energy (electricity) out of battery:

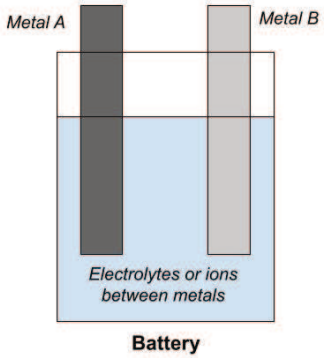
- *is a result of interactions between different metals separated by ions, usually as a solution of electrolytes.*
- *results in electrons flowing through wires and an electrically powered device connected to each end of the battery.*

Batteries

Similarities:
- Cathode and anode
- 2 different types of materials as ends, usually metals
- Involve same kind of **matter**:
  - Electrons
  - Ions in middle
  - Metals

Differences:
- Shapes
- Amount of space between the anode and cathode
- The AA and car batteries contain a solution where the ions travel across.
- The ions in the lithium ion battery travel across a metal oxide and graphite.
- Different combos of metals

Model for Explaining Energy Transfer in a Battery



Display **slide K.** Encourage students to add to their copy of *Battery Model* when you update the "Batteries" poster.

ADDITIONAL GUIDANCE

Briefly refer back to what you learned in *Electrostatics Unit* if students are unsure how to represent electricity in their models.

Share initial ideas about energy. Suggest that the class brainstorm how different combinations of parts would affect the energy transfer of the battery we make. Display **slide L** and have students discuss the prompts for one minute. Accept all responses, but some likely ones are shown.

Suggested prompt	Sample student response
What do you think would happen if we tried different materials in the battery?	Different amounts of energy might pass through the wire. The voltage of the battery might change.
How could we measure changes in energy transferred when we switch out materials?	We could use an ammeter or a lightbulb to see the energy flowing through.

Say, *Let's see if we can test some of your ideas.*

4 · DEMONSTRATE THE VOLTMETER

5 min

MATERIALS: Voltmeter Demonstration

Recall prior use of the ammeter. Display **slide M.** *Say, Let's recall some of the equipment we used in Electrostatics Unit and think about how we can reuse it to figure out what is going on with the energy inside of a battery. Current, or charges per second, is one of the measures used to determine how much energy is being transferred out of a battery.* Hold up the ammeter/voltmeter students will be using. Discuss the questions on the slide.

Suggested prompt	Sample student response
How did we use this equipment to measure the current from a battery in a prior unit?	We hooked it up to two metal pieces in water and measured the amount of current that moved through the water when we added different amounts of salt to it.
What did this help us figure out?	The salt concentration in the water affected the current through it. Higher salt concentrations produced higher current flow. There was no current through distilled water.

Say, *When we used an ammeter, we measured the current traveling through the system in amperes. Seeing the data helped us argue that when current increases, the amount of energy transferred through the salt water increases. If there is no current, no energy is being transferred. But current alone is not all that scientists use to determine how much energy is transferring out of a battery.*

Recall examples of different voltages. Display **slide N.** Say, *Voltage is a second measure that is used to determine the amount of energy that a battery is transferring out of it. Voltage measures the amount of energy that will be transferred out of the electric field and into the surroundings when moving one electron from the anode to the cathode. The rate of energy transferred out of a battery and into an electrical object is the current times the voltage.* Ask, *What are examples of different amounts of voltage (V) you have seen labeled on different types of batteries?* Look for students to mention: 1.5V, 9V, 12V, or 18V.

ADDITIONAL GUIDANCE

The mathematical relationship shown on **slide N,** *current × voltage = rate of energy transfer*, is included simply to help support the idea that both current and voltage contribute to the rate of energy transfer in a part of an electrical system. This is designed to help motivate students to collect voltage and current data as proxies for the amount of energy transfer. Emphasize that these ideas connect to energy, as students will have opportunities to think about the mathematical relationship more in *Electricity Unit*.

Complete the Voltmeter Demonstration. Display **slide O**. Hold up the voltmeter and turn it on. Say, *This device has been modified so that it can also measure voltage. To use it as a voltmeter, you will make use of the new yellow connection wire along with the black connection wire. Let's connect each of these to the two different ends of a single AA battery to see what voltage this battery will provide between these two points in space.*

SAFETY PRECAUTIONS

Prevent the ends of both wires with alligator clips (connected to either end of the battery) from touching at all times. If the ends touch, this will short circuit the battery and cause it to heat up quickly, which can be a potential fire hazard.



Attach one alligator clip to the end of the yellow wire lead on the voltmeter and tape it against the positive end of the battery. Attach another alligator clip to the end of the black wire lead on the voltmeter and tape it against the negative end of the battery. If it is a new battery, the output should be at or slightly above 1.5 volts. Note that used batteries that are not fully drained may have a lower output.

Explain that the voltmeter is sensitive to the direction that a current would flow between the two points connected to it and will register a non-zero value from a working battery only when the yellow and black wires are attached to the correct ends of the battery. Demonstrate this by switching the wires' connections. Explain that this means that in their own investigation, students will need to try switching the wires' connections on the voltmeter if they get a zero reading. Remind students that they will jump right into collecting data from the investigation when they come back next class.

End of day 1

5 · COLLECT VOLTAGE DATA ON DIFFERENT METALS IN BATTERIES

12 min

MATERIALS: Measuring Electrode Voltages Investigation

ADDITIONAL GUIDANCE

Use the information contained in *Electrode Station Setup* to set up the 7 stations for this activity.

Prepare for an investigation of energy and matter. Display **slide P**. Explain that students will use the voltmeter part of the device you demonstrated last class to measure the voltage between two metals placed in an electrolyte solution, and they will try this for seven different metal combinations by rotating through each station.

Distribute a copy of *Measuring Voltage Procedure* to each student. Give students a minute and a half to read through the procedure. Address any clarifying questions.

Ask students to make a prediction about what they will see during the investigation. Say, *How do you think the type of matter (different metals) will affect the energy transferred (voltage) in the system?* Encourage students to share their predictions with their group as they begin the investigation.

Review safety protocols. Display **slide Q** and review the safety protocols there.

SAFETY PRECAUTIONS



- Wear indirectly vented chemical splash goggles, non-latex apron and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Immediately wipe up any spilled water on the floor--this is a slip-and-fall hazard.
- Follow procedures set up by your instructor for disposal of materials.
- Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Prevent the ends of both alligator clips connected to either end of the battery from touching in this activity. This will short circuit the battery and cause it to heat up quickly, which can be a potential fire hazard.
- Keeping the battery connected to wires can cause overheating. Only use for a short time. Disconnect if wires are heating up quickly.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Use caution with working with wires - these are considered sharps and can scratch or cut skin.
- Use caution when working with glassware or plasticware--can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Direct supervision will be required during all aspects of this activity.

Carry out an investigation of energy and matter. Display **slide R**. Have students create a data table in their notebooks using the template on the slide. Give groups about seven minutes to complete the investigations at the seven stations using the directions on *Measuring Voltage Procedure*. You may announce for groups to rotate to the next station after one minute. Monitor the stations to make sure the bottoms of the electrodes at each station do not touch, as this will yield a voltage of 0. Separate them if they are touching.

Collect *Measuring Voltage Procedure* to reuse with your next class as students head back to their seats.

ADDITIONAL GUIDANCE

During or after the investigation, some students may ask about other metal combinations mentioned in the Fuel Data Cards about batteries. Explain that many of these materials are very costly or dangerous to use within the classroom. Tell students that the materials they are using are classroom appropriate.

6 · ANALYZE RESULTS AND DEVELOP AND USE A MODEL

7 min

MATERIALS: *Battery Model*, science notebook, "Batteries" poster, chart paper markers

Analyze the results. Display **slide S**. Give students a half minute to consider the questions on the slide on their own, and then discuss these as a class. Sample findings are shown in *Electrode Station Setup* and are also listed here:

• Station 1: Al and Al = 0.0V • Station 2: Al and Zn = 0.4V • Station 3: Al and Fe = 0.3V	• Station 4: Al and Cu = 0.6V • Station 5: Cu and Cu = 0.0V	• Station 6: Cu and Zn = 0.9V • Station 7: Cu and Fe = 0.5V

Suggested prompt	Sample student response
What matter (combination of metals) provides the highest amount of energy per electron (voltage) that moves in the system?	Copper and zinc together produce the highest voltage.
How can we explain the results for Stations 1 and 5?	The metal for the cathode and anode was the same in Station 1 (aluminum) and in Station 5 (copper). This means the system does not transfer any energy per charge.

Explain the systems using a forces lens. Display **slide T**. Read aloud the text at the top of the slide:

- Even though electrons in solid metals are not strongly held to any one nucleus, some metal nuclei exert stronger attractive forces on these electrons than other metal nuclei.

Ask, *What are some things we know about the structure of an atom that would influence how strongly it attracts electrons?* Look for student responses such as:

- *The number of protons it has.*
- *The number of electrons in its outer shell.*
- *Its atomic radius.*
- *Its row or column in the periodic table.*
- *Electronegativity.*

ADDITIONAL GUIDANCE

It is important that students mention electronegativity. If they do not, prompt them to think back to *Space Survival Unit* and to Lesson 7 in this unit.

Connect the forces to energy in a battery. Display **slide U** and point out the electronegativities of the metals used in the batteries investigation. Discuss the three prompts as a class.

Suggested prompt	Sample student response
Why are electrons not pulled toward one of the metals in Stations 1 and 5?	They are the same type of atoms in both metals, so the attractive forces they exert on electrons would be the same.
At other stations, which metal is pulling more on the electrons? Why?	The second metal, or Metal B, or the cathode. The one with the greater electronegativity. The metal with a higher electronegativity has a stronger pull because it has more protons relative to its electron shells.
What stations transfer the most energy? Explain using what you know about forces.	The copper-zinc battery has the highest voltage. The electronegativity difference between copper and zinc is high. The stronger the forces to move electrons, the greater the energy transferred.

Describe the role of the wires. *Say, We use metal wires to form a circuit. These wires connect the electrically powered device to both electrodes in a battery. The electrons in the metal wires connecting the two electrodes provide a sort of tug-of-war rope across which forces can act. A stronger pull on the electrons in the wire connected to the cathode rather than the anode can result in electrons starting to move from the wire toward the cathode, which results in electrons being pulled away from the anode.*

Update the "Batteries" poster to include the connection to forces and energy, as shown in the image. Remind students to include these ideas on their copy of *Battery Model* to keep track of the new information they have figured out.

Batteries

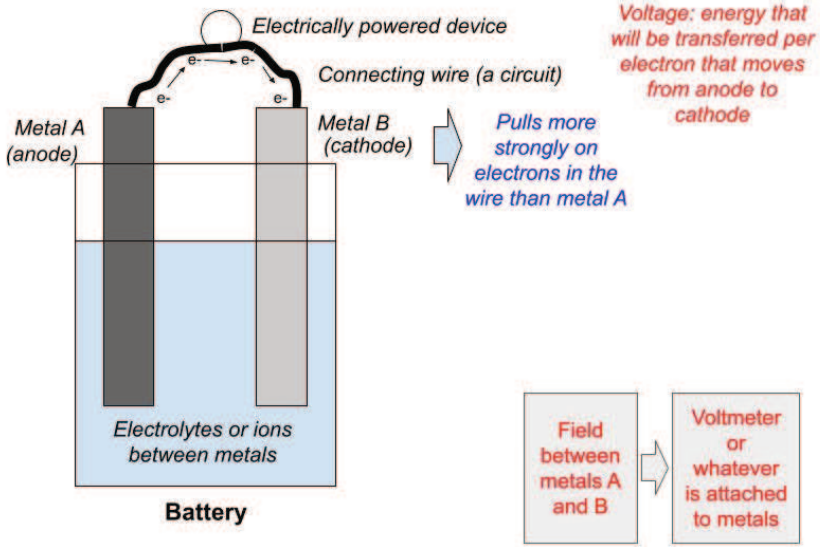
The transfer of energy out of battery:

- ➔ Is a result of interactions between different metals separated by ions, usually as a solution of electrolytes.
- ➔ Results in electrons flowing through a wire and an electrically powered device connected to each end of the battery

Similarities:
- Cathode and anode
- 2 different types of materials as ends, usually metals
- Involve same kind of **matter**:
  - Electrons
  - Ions in middle
  - Metals

Differences:
- Shapes
- Amount of space between the anode and cathode
- The AA and car batteries contain a solution where the ions travel across.
- The ions in the lithium ion battery travel across a metal oxide and graphite.
- Different combos of metals

Model for Explaining Energy Transfer in a Battery



7 · CONSIDER ELECTROLYTES IN BATTERIES

10 min

MATERIALS: *Battery Model*, "Batteries" poster, table salt, cup of water, chart paper markers

Brainstorm reasons a battery would need electrolytes.✱ Display **slide V**. Have students turn and talk to consider the two prompts on the slide, then have students share their ideas with the class.

Suggested prompt	Sample student response
We have metals in a battery, but why do we need a solution of electrolytes for the electrons to move through the wire?	Accept all answers.
What could we change about the electrolyte to make the battery transfer more energy and therefore improve our battery design?	Accept all answers.

Problematize the need to understand the electrolyte solutions in batteries. Say, *In order to come up with the best battery design we need to understand all the components of the battery, including the electrolytes and ions sandwiched between our anode and cathode.*

ADDITIONAL GUIDANCE

It is important that students have some experience with ionic compounds and electrolytes from *Electrostatics Unit* and *Space Survival Unit*. Refer back to what students figured out during these units to help them build on this prior knowledge.

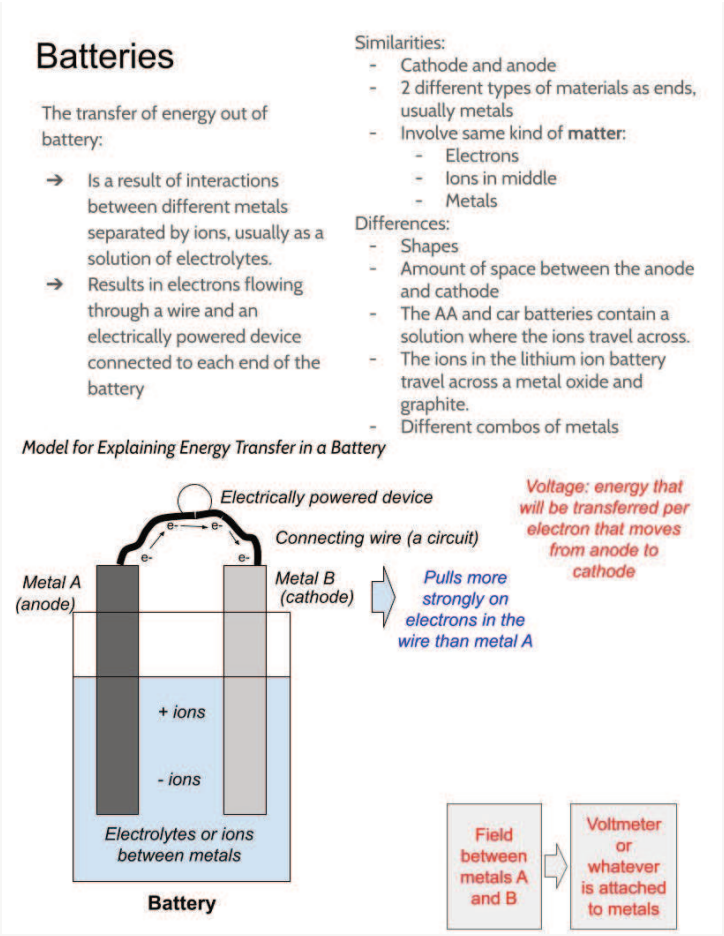
Revisit prior knowledge of electrolytes. Display **slide W.** Have the "Batteries" poster visible. Lead a discussion to review what we know happens when a small amount of a salt dissolves in water. Hold up a sample of salt and a cup of water.

Suggested prompt	Sample student response
What will happen when I take a small amount of table salt at room temperature and stir it into water?	It will dissolve and the ions will separate.
Do all ions have the same charge?	No, some are positive and some are negative. Different types of ions can have different charges, like K^+ vs. Ca^{2+}, Cl^-, or O^{2-}.

Update the "Batteries" poster to include the ideas that electrolytes in solution are positively and negatively charged ions. Remind students to include these ideas on their copy of *Battery Model* to keep track of the new information they have figured out.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

While not explicitly assessed as part of this lesson, students should think about how *changes in the way matter flows* or the *types of matter* found in the *battery system* impact the *energy that is released by the system*. (CCC: 5.2)

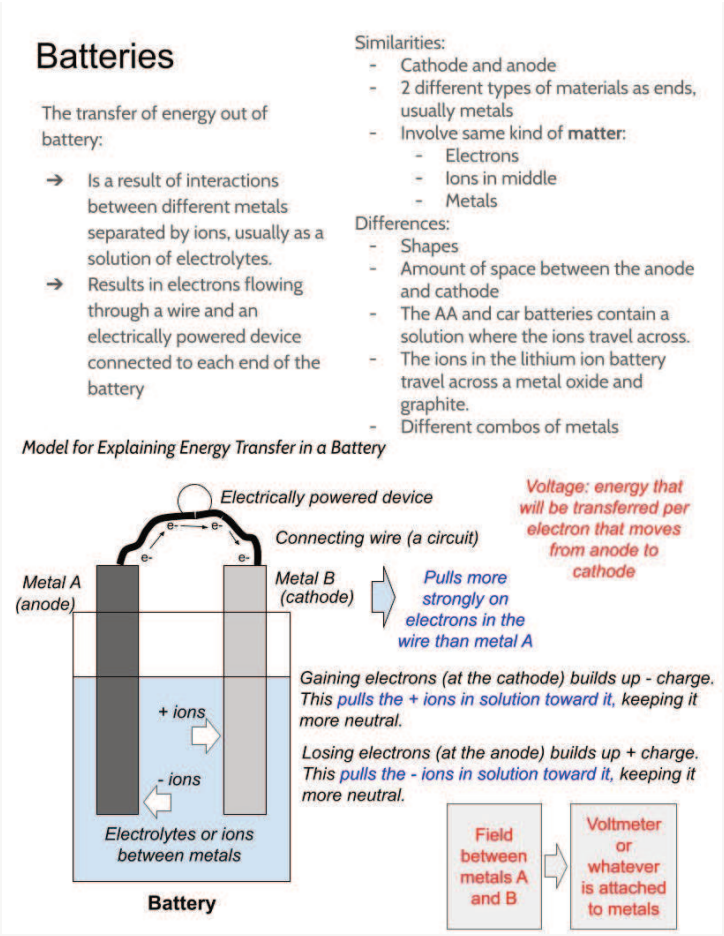


Track electrolytes in a battery. Display **slide X.** Have students consider a matter and forces perspective. Say, *There are electrolytes in the solution between the electrodes (metals) in a battery. How might these ions be moving to keep a battery running longer?* Give students two minutes to work with a partner to consider the movement of electrolytes in a battery by tracing their fingers on their copies of *Battery Model*. One student should track where positive ions go, while the other student should track where negative ions go.

Include movement of electrolytes in the model. Display **slide Y.** Refer to the prompts on the slide to elicit students' observations from the previous step.

Suggested prompt	Sample student response
In your tracking of electrolytes, where did you show the positive and negative ions moving in the battery?	Positive ions would move toward anything that is negative. Negative ions move toward things that are positive. I'm not sure which ends of the battery are attracting the positive or negative ions.
Why would charges be moving through the solution?	Charges are attracted to things of the opposite charge. The metals might develop a buildup of charge if electrons are moving through the wire. The anode and cathode might be positive and negative, since I have seen batteries labeled that way before.

Update the "Batteries" poster to include these ideas. Remind students to include these ideas on their copy of *Battery Model* to keep track of the new information they have figured out.



ADDITIONAL GUIDANCE

Students may comment on the fact that batteries are often labeled with a positive and negative side. If they mention that this helps indicate which side is the cathode and which is the anode, suggest that it seems like it should and encourage students to write that down rather than try to map which side is which according to the labeling convention.

This labeling convention adds a layer of complexity to the model that is not needed. The historical convention for batteries was to label the electrodes to indicate the side the positive ions in the solution would flow toward as positive (the cathode). This was established before evidence of the role of the electron was discovered in electrostatics. The latter might have led to flipping the labeling convention on batteries.

Consider why batteries die. Display **slide Z.** Say, *I am hearing you say that the electrolyte must be carrying charges between the ends of the electrodes in the battery. Do you think that movement could continue forever? Let's consider the electric field and the forces perspective.* As you discuss the prompts on the slide, listen for suggestions that ion movement cannot continue forever; it must reach a stopping point and then

the battery needs to be recharged or will not work.

Suggested prompt	Sample student response
Based on the flow of electrons in the wire, which ions are pulled toward the cathode? The anode?	If electrons are flowing from the anode through the wire to the cathode, that makes the metal at the cathode more negative, so the positive ions might flow toward that too. The anode is losing electrons, so it would become positively charged, leading to an attraction of the negative ions in that direction.
How does the movement of ions in the solution affect the electric field in the system?	When the oppositely charged ions are at the cathode and anode respectively, we see charges start to "cancel each other out." The strength of the electric field gets weaker.
As more and more ions cancel out the charge buildup at the anode and cathode, how will that affect the flow of electrons through the wire?	Electrons are still going to flow because one of the metals is more electronegative than the other. The charge buildup without the ions would have prevented electrons from wanting to move to the cathode because it would get increasingly negative, repelling the electrons.

8 · ANALYZE ELECTROLYTE DATA AND REVISE BATTERY MODEL

5 min

MATERIALS: *Electrolyte Current Data*, *Ion Concentrations* (optional), *Battery Model*, "Batteries" poster, chart paper markers

Consider how the amount of electrolytes affects the energy output in a battery. Summarize takeaways from the previous step of tracking electrolyte movement in the battery, then display **slide AA.** Pose the question of how the amount of electrolytes may affect a battery. Say, *In Electrostatics Unit we added salt to create different solutions and measured the rate that charges flowed through each one, also known as the current. How might changing the amount of salt added to a solution affect the current?* Accept all ideas.

Suggested prompt	Sample student response
How might increasing the amount of electrolytes affect the current (rate of charge movement)?	Adding more salt would increase the current.
How would that affect the energy in the battery?	A greater current means energy flows more quickly.

Say, *Let's look at some data to see if that does happen and if it could help with our battery designs.*

Analyze electrolyte data in batteries. Display **slide BB**. Distribute *Electrolyte Current Data* and have students analyze the data in pairs for a minute or two before discussing it as a class.✱

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

Students analyze data to determine which electrolytes produce the greatest rate of energy transfer in milliamps to develop an optimal design solution for their batteries.

Suggested prompt	Sample student response
Which electrolyte solution would create a battery with the highest energy output? Why?	The calcium chloride solution. With a greater current, more charges would be able to move to cancel out the charge buildup from the wire, allowing for more energy to flow through the system.

ADDITIONAL GUIDANCE

The goal of this brief analysis is to activate additional prior knowledge from the last three units of this course. An optional analysis of a more complex (expanded) set of this data following the initial analysis is on **slide CC**. The optional analysis is useful to consider the stoichiometric relationships between the ions in a solution and the current.

Optional: Problematize the need to look at more data. Say, *But if you look at the salts in the data table in front of you, they all have the same molarity, which seems like they should have the same concentration of ions in solution. But that would not explain why the current is higher for some of these solutions than for others.*

Say, *Let's see what patterns we notice if we look at the calculations used to determine how many of each type of ion is produced for each salt solution.* Display **slide CC** and distribute *Ion Concentrations*. Explain that the last two columns show the results of those calculations, while the column before shows how the calculations are determined using molar mass and what we know about some of the atoms from the periodic table.

Give students four minutes to discuss the question on the slide with a partner. Then discuss it as a class and follow up with the second question below.

ALTERNATE ACTIVITY

Slide CC is optional and easily modified based on your students' needs. It is projected to take an additional 10 minutes of class time. The provided reference has all the calculations completed so that students can focus on the patterns in the last two columns of the table. You could modify this reference to have students perform some of the calculations themselves. For example, you might remove the content in rows 2 and 3 and have students perform the calculations for magnesium sulfate and potassium chloride in pairs (each partner focusing on one solution), using rows 1 and 4 as worked examples. A video example can also be found at: https://www.youtube.com/watch?v=7fHA17DOrBg.

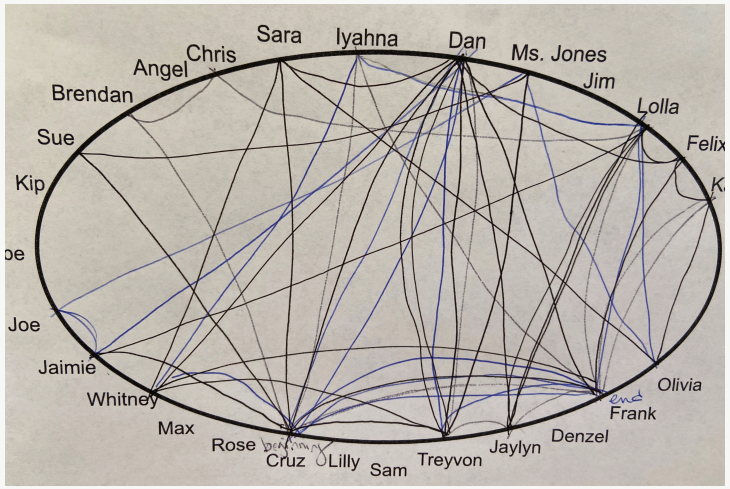
Suggested prompt	Sample student response
How can these calculations help us explain the differences in the maximum current for each electrolyte solution?	The solutions that produce higher current have more ions in them.
If we made sure that the total number of ions in solution was the same for each salt we test, do you think the type(s) of atoms in each ion would affect the current through the system?	Accept all answers.

ADDITIONAL GUIDANCE

Surface area and distance between electrodes also play a role in the rate at which current flows inside a battery. Some students may wonder about these phenomena. Encourage students to record any related questions and add them to the Driving Question Board, as they reflect important engineering considerations.

This engineering consideration is beyond the scope of the unit: *Maximum current flow that a battery can provide is a limiting factor in how much energy can be transferred out of it in a given amount of time (Joules per second), and operating a battery too close to its maximum current flow tends to degrade its rechargeability and overall lifespan as well as produce a lot of excess heat within the battery.*

Revise the "Batteries" poster. Display **slide DD**. Work with students to revise the model to include the new ideas shown. Remind students to include these ideas on their copy of *Battery Model* to keep track of the new information they have figured out.



ADDITIONAL GUIDANCE

You do not need to explain the additional matter transformations that happen to the positively charged atoms on the surface of Metal A at the anode, or to the excess electrons and positive ions around the cathode.

9 · DEVELOP BATTERY DESIGN PROPOSAL AND SUMMARIZE FINDINGS

10 min

MATERIALS: *Battery Design Proposal*, *Electrolyte Current Data*, Progress Tracker, *Electronic Exit Tickets* from Lesson 5, "Batteries" poster, M-E-F poster

Make a battery design proposal. Display **slide EE**. Suggest that the combination of the electrolytes we analyzed today and the metals we measured yesterday give us the kind of data that engineers use to figure out how to design more effective batteries. Tell students to draw on the electrolyte data and their investigation data to support a battery design proposal they would make to answer the question:

- Which two metals and electrolyte solution combined should produce the highest rate of energy output in a battery?

Remind students that after supporting their design proposal with evidence, they should also be able to explain a mechanism or series of mechanisms for it–the how and the why. Remind students to draw on the "Batteries" poster and their M-E-F poster thinking for this part of their design argument. Have students complete their design proposals in their science notebooks or use *Battery Design Proposal*.

ADDITIONAL GUIDANCE

If students struggle to identify the cascade of steps that would result in the highest rate of energy transfer out of the battery, give them a minute to turn and talk with a partner while prompting students to think about this using the M-E-F poster. A possible prompt could be: *Using the M-E-F poster, discuss how the matter and force interactions occurring in the battery system enable it to transfer energy to an electrically powered device connected to the wires between the anode and cathode.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students explain that a battery transfers electrons between two different substances through a wire to generate an electric current. (DCI: PS3.A.4, CCC: 2.2)
- Students explain that electrolytes in the battery break into ions which move through water to generate an electric current (energy). (DCI: PS3.A.4; CCC: 2.2)
- Students identify specific pieces of investigation data and evidence from *Electrolyte Current Data* to support their proposed battery design. (SEP: 6.5)
- Students explain that their design has a higher ion concentration and therefore greater energy output. (DCI: PS3.A.4; CCC: 2.2)
- Students explain that the chosen metal combinations contain one metal that is better at releasing their electrons and one metal that is better at gaining electrons, which results in greater energy output. (DCI: PS3.A.4; CCC: 2.2)

What to do: See *Battery Design Key*.

Building toward 9.B Use evidence from student investigations and research to propose a battery design that results in the largest energy output based on the types of solutions and metals used in the battery and the matter and force interactions between them. (SEP: 6.5; DCI: PS3.A.4; CCC: 2.2)

ALTERNATE ACTIVITY

Extension opportunity: If you have time, you could conduct a voltmeter demonstration for two of the combinations of solutions and metals that students decided would result in the highest energy output. (CCC: 2)

Update Progress Trackers. Display **slide FF** and recall what students accomplished in the Scientists Circle. Say, *The purpose of our discussion was not to decide whether EVs are "good or bad," but to identify the important considerations of using this technology as a way to fuel our transportation. Let's identify how we can summarize our takeaways from the discussion using the* Avoid, Shift, Improve *framework in our Progress Tracker.* A sample Progress Tracker entry is shown.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	**Engineering implications** Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
As we saw in investigations and diagrams, batteries are made of a solution containing ions and two different metals on either side of the solution. The metals need to have different electronegativities which helps attract ions to one side of the solution more than the other. This creates a difference in the concentrations of charges (forces) in the solution. Because of this, there is more energy stored in the fields within the solution which leads to a greater energy output.	*Batteries are promising as a fuel, especially because driving EVs with batteries doesn't have any "tailpipe" emissions, unlike all of the fuels we have investigated before.* *However, it does require the use of more metals and electricity, which could pose other issues. Batteries have to get better for EVs to work more broadly.*	Avoid: *Avoid personal vehicles (including EVs) when possible, because they are not harmless to the environment. Making and using any kind of vehicle will emit some CO_2 and require the extraction of resources from the environment.* Shift: *Shift toward EVs because, on the whole, they are becoming increasingly accessible and generally seem better for the environment (even if they aren't perfect).* Improve: *Improve by creating batteries with better energy output that potentially use less harmful materials. Also, find ways to recycle the materials used to make batteries so we extract from the environment less.*

ALTERNATE ACTIVITY

If you are limited on time, you could have students update the Progress Tracker based on what they know about the structure of batteries and how that could help improve battery designs in EVs.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify that batteries and EVs can be used to reduce pollution but still have an environmental impact, and that these concerns could be partly addressed by improving batteries. (DCI: ESS3.C.2; CCC: 2.3)
- Students consider explanations of how batteries work as they evaluate electric vehicles as a design solution. (SEP: 7.1)

What to do: Pay particular attention to the Progress Tracker entries of students who did not speak much during the Scientists Circle associated with this LLPE. Encourage students to tie the ideas they figured out about how batteries work to batteries' advantages and disadvantages, and look for students to suggest ways in which the transportation system can be designed to leverage electric vehicles' positive environmental and other impacts and reduce their negative impacts.

Building toward 9.A.2 Compare and evaluate arguments about a new transportation technology (batteries and EVs) to reduce pollution while considering its impact on the transportation system. (SEP: 7.1; DCI: ESS3.C.2; CCC: 2.3)

10 · NAVIGATE

1 min

MATERIALS: Fuel Data Cards from Lesson 1 (optional)

Navigate to the next lesson. Display **slide GG**. Ask, *What other non-carbon-based fuel sources were we wondering about?* Look for students to say hydrogen. If students say uranium, ask which substance has more in common with the technologies we have already considered. Use Fuel Data Cards as needed, and guide students toward the idea that because hydrogen is used in some personal vehicles, it might make more sense to investigate hydrogen next.

ALTERNATE ACTIVITY

Extension opportunity: As with other non-fossil fuel technologies, job opportunities related to electric vehicles are on the rise. Direct interested students to https://www.bls.gov/green/electric_vehicles/#occupations to research this topic further.

Additional Lesson 9 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.8: 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.

Students use text to compare the advantages and disadvantages of using batteries and electric vehicles as a future transportation option.

LESSON 10: How can we use hydrogen as a fuel and what are the impacts?

PREVIOUS LESSON

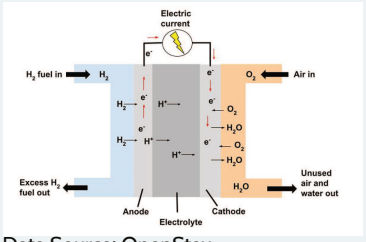
We evaluated arguments about electric vehicles. We analyzed images of the components found inside different batteries. We collected data on the voltages produced by different metal electrodes. We analyzed data on the current produced by different electrolytes.

THIS LESSON

INVESTIGATION

1 day





Data Source: OpenStax

We identify similarities between hydrogen fuel cells and batteries and engines. We examine data on global hydrogen production and wonder about greenhouse gasses. We analyze and interpret gas data and molecular models to understand why some gasses are greenhouse gasses. We revisit our criteria and constraints, research the locations of hydrogen and charging stations, and update our Progress Trackers.

NEXT LESSON

We will analyze the structure of a nuclear reactor and apply M-E-F lenses to nuclear fission. We will analyze data on protons and neutrons and read about the strong nuclear force. We will jigsaw articles that describe concerns with uranium as a fuel, update our Progress Trackers, and complete an Electronic Exit Ticket.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1



WHAT STUDENTS WILL DO

10.A Analyze data about greenhouse gasses from hydrogen production and evaluate their impact on the transportation system to optimize it relative to criteria of greenhouse gas emissions to preclude ecosystem degradation. (SEP: 4.5, 4.6; DCI: ETS1.A.1, ESS3.C.2; CCC: 2.3)

WHAT STUDENTS WILL FIGURE OUT

- Hydrogen fuel cells are similar to batteries in that they directly produce electricity and similar to engines in that they have inputs (hydrogen and oxygen) and outputs (water).
- Most hydrogen is produced from fossil fuels in a process that also emits carbon dioxide.
- Greenhouse gasses persist in the atmosphere and wobble (vibrate) a lot when they absorb infrared radiation emitted by Earth.
- Some special criteria and constraints must be considered with hydrogen fuel cells for transportation (not enough refueling stations, greenhouse gas emissions during hydrogen production).

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	1 min		**NAVIGATION** Return to the DQB as a class and consider which fuels we have not answered questions about yet.	A	*Progress Tracker* from Lesson 2, Driving Question Board
2	6 min		**EXAMINE HYDROGEN FUEL CELLS** Organize students into groups to examine a set of selected fuel cards. Compare hydrogen fuel cells to batteries with a partner and discuss similarities and differences.	B-F	Set of selected fuel cards from Lesson 1, *Hydrogen Fuel Cells*, *Comparing Different Batteries* from Lesson 9, "Batteries" poster from Lesson 9, https://youtu.be/VI4Fz_bv1dw (optional)
3	5 min		**HYDROGEN PRODUCTION** Examine hydrogen production methods from a criteria and constraints perspective, then discuss as a class.	G	
4	14 min		**ANALYZE AND INTERPRET ATMOSPHERIC GAS DATA** Revisit greenhouse gasses as a class, analyze and interpret atmosphere gas data with a partner and discuss data as a class.	H-L	*Atmosphere Gas Data*
5	7 min		**EXPLORE MOLECULAR VIBRATION** Analyze vibration patterns in molecular models of atmosphere gasses in groups and discuss them as a class.	M-P	Set of gas molecule models
6	7 min		**REVISIT CRITERIA AND CONSTRAINTS** Organize students into small groups to brainstorm initial ideas about why battery and hydrogen fuel cell vehicles are not used more often. Have the groups research locations of charging and hydrogen fuel stations.	Q-S	*Fuel Energy Released*, *Progress Tracker* from Lesson 2, internet-connected device, https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY, https://chargehub.com/en/charging-stations-map.html, "Criteria and Constraints" poster from Lesson 1, chart paper markers
7	5 min		**NAVIGATE** Have students work with a partner to update the Progress Trackers with their findings about using hydrogen fuel cells for transportation. Navigate to the next lesson by thinking about other non-carbon-based fuels.	T-U	*Progress Tracker* from Lesson 2

End of day 1

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials	• *Progress Tracker* from Lesson 2 • science notebook • *Atmosphere Gas Data* • *Fuel Energy Released*	• Set of selected fuel cards from Lesson 1 • *Hydrogen Fuel Cells* • *Comparing Different Batteries* from Lesson 9 • Set of gas molecule models • internet-connected device • https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY • https://chargehub.com/en/charging-stations-map.html	• Driving Question Board • "Batteries" poster from Lesson 9 • https://youtu.be/VI4Fz_bv1dw (optional) • "Criteria and Constraints" poster from Lesson 1 • chart paper markers

Materials preparation (60 minutes)

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

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

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

Have the following visible:
- "Batteries" poster from Lesson 9
- "Criteria and Constraints" poster from Lesson 1
- DQB

Create seven sets of selected fuel cards from Lesson 1:
- gasoline
- lithium-ion batteries
- hydrogen

Print color copies of *Hydrogen Fuel Cells* and *Atmosphere Gas Data* on cardstock. Print at least one of each per pair of students.

Have color copies of *Comparing Different Batteries* available, at least one per pair of students.

Test this video if you wish to use it for an alternate activity: https://youtu.be/VI4Fz_bv1dw

Follow the instructions in *Assembling Molecular Models* to build seven sets of gas molecule models from different-sized styrofoam balls and pipe cleaners. You will need one set per group of 5 students. To save time, you can also distribute the materials and copies of *Assembling Molecular Models* to your first class and instruct them to build the molecular models.

Use https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY to make note of options to refuel hydrogen fuel cell vehicles in your area.

Use https://chargehub.com/en/charging-stations-map.html to make note of options to recharge electric vehicles in your area.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS3.C.2 Human Impacts on Earth Systems:** Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
- **ETS1.A.1: 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.

Crossout explanation: Students previously reflected on producing less pollution and waste in Lesson 9, an idea they are building on here. They developed ETS1.A.1 in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, and will continue to quantify criteria and constraints in Lesson Set 3.

Students examine hydrogen fuel cells and determine how they are similar to and different from the batteries they learned about in Lesson 9. Like batteries, hydrogen fuel cells also have an anode, a cathode, and an electrolyte and generate electricity.

Students *analyze data* about the production of hydrogen from a *criteria and constraints perspective* and realize that most of the hydrogen currently produced comes from methane with carbon dioxide as a by-product. (SEP: 4.5; DCI: ETS1.A.1)

When students revisit the methane fuel card, they see that methane is a *stronger greenhouse gas than carbon dioxide, and there is a chance of it leaking into the atmosphere* at all stages of its lifecycle. This leads them to explore additional atmospheric gas data (global warming potential and lifetime) to understand which gasses act as greenhouse gasses and why (SEP: 4.5; DCI: ESS3.C.2). They previously evaluated the impact of new data on their model in Lessons 3 and 4.

Although the lifetime of a gas in Earth's atmosphere and its ability to absorb infrared radiation emitted by Earth seem to play a role in its global warming potential, they do not explain why methane is a stronger greenhouse gas than carbon dioxide. To answer this question, students examine the ability of molecular models of atmospheric gasses to vibrate upon the addition of absorbed energy. Students notice that methane wobbles or vibrates more than carbon dioxide, which vibrates much more than nitrogen or oxygen. This builds upon the model for climate change that the class began building in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

Students close the lesson by analyzing data about hydrogen fuel and EV charger availability and update their Progress Trackers to tie *science ideas from this lesson to engineering implications for the transportation system*, including risk mitigation (e.g., minimizing emissions from escaped methane) (SEP: 4.6; DCI: ETS1.A.1; CCC: 2.3). Students last applied data to characteristics or components of the transportation system in Lesson 2.

Where We Are NOT Going

In this lesson, students explore a generic fuel cell and the overall chemical reaction that occurs in it to gain a basic understanding of how fuel cells generate electricity. The full mechanism behind how a fuel cell works is beyond the scope of this unit, given that its parallels to batteries address students' questions about how fuel cells work.

Students' examination of infrared-active vibrational transitions is limited to a qualitative assessment of a molecule's ability to vibrate through the use of molecular models. A detailed explanation for the absorption and transmission of particular wavelengths of light based on electronic transitions in the atom is beyond the scope of the unit and is beyond the targets for NGSS for high school.

In Lesson 4 of this unit, students figured out that if the energy added to a molecule is not enough to break bonds, the bonds will wobble. The wobble is caused by energy moving in and out of the fields between atoms in the gas molecule. The energy transfer from this wobbling action is not modeled in detail in either lesson but will support student thinking in Lesson 11.

At this point in the OpenSciEd High School sequence, students' understanding of light is limited to light as energy. They have not yet developed a conceptual understanding of the variation of light's energy with frequency or wavelength. This will not be developed until the Physics course. Discussion of wavelength is limited to the numerical value which corresponds to a "color" of infrared light, but there is no further development of understanding of infrared light beyond what students developed in High School Chemistry *Polar Ice Unit*. In-depth development of the electromagnetic spectrum is covered in *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*. In this unit, students will also fully develop their model of greenhouse gasses to explain why they absorb infrared light but not visible light.

LEARNING PLAN for LESSON 10

1 · NAVIGATION

1 min

MATERIALS: *Progress Tracker* from Lesson 2, Driving Question Board

Leverage the DQB to review what we have figured out. Display **slide A**. Use the prompts on the slide and the DQB to facilitate a brief discussion. Encourage students to refer to their *Progress Tracker* from Lesson 2. As students share ideas about carbon-based fuels and batteries, make connections to those categories on the DQB.

Suggested prompt	Sample student response
What types of fuels have we looked at so far?	Gasoline and diesel–fossil fuels. Carbon-based fuels. Biofuels. Batteries.
How do they satisfy the criteria and constraints we established for use in our transportation systems?	Fossil fuels are the most common. They have high energy released but emit carbon dioxide. Biofuels have lower emissions and pollution but do not release as much energy per mole. There aren't any emissions from vehicles with batteries, but they require the use of metals and electricity.

Navigate into hydrogen fuel cells. Ask the class which other non-carbon-based fuels they had questions about. Use the DQB to navigate into exploring hydrogen. Say, *So we have figured out how batteries work to provide energy to power vehicles, but a few classes back we also identified two other non-carbon fuels to examine. One of those was hydrogen.*

2 · EXAMINE HYDROGEN FUEL CELLS

6 min

MATERIALS: science notebook, Set of selected fuel cards from Lesson 1, *Hydrogen Fuel Cells*, *Comparing Different Batteries* from Lesson 9, "Batteries" poster from Lesson 9, https://youtu.be/V14Fz_bv1dw (optional)

ADDITIONAL GUIDANCE See the "Materials preparation" section for instructions on which fuel cards from Lesson 1 should be part of the selected set for groups to examine.

Revisit fuel cards. Say, *Let's revisit the fuel cards for the fuels we have already investigated—gasoline and lithium-ion batteries—as well as hydrogen.* Present **slide B** and hand out sets of selected fuel cards from Lesson 1 to each group. Ask students to review the cards through the lens of the prompts on the slide. After students have had two minutes to examine the cards, bring the class back together to share their ideas.✱

✱ ATTENDING TO EQUITY

Supporting multilingual learners: To provide additional language practice with communicating their ideas as they work, consider having one partner say ideas while the other writes for 1 minute, then switch roles.

Suggested prompt	Sample student response
How does hydrogen compare to gasoline and lithium-ion batteries in terms of our criteria?	There are no CO_2 emissions, just like batteries. The only emission listed is water. It seems like carbon-based fuels are involved in making hydrogen, and sometimes CO_2 is a by-product. So that's not good. The energy released of hydrogen is only 242 kJ/mol versus 6,140 kJ/mol for gasoline. But it's possible to store lots of small hydrogen molecules under pressure.
How does it compare in terms of constraints?	Well, if it can be used to move spacecraft, it can certainly be used in big vehicles! Hydrogen is a gas, so it probably would not work with the vehicles we have that currently run on liquid gasoline. It's relatively cheap to produce.

Compare hydrogen fuel cell design to battery design. Acknowledge that hydrogen sounds like a promising fuel but that we need to learn more about it. If it has not come up already, point out that the fuel card for hydrogen mentions that personal vehicles use something called a *hydrogen fuel cell.* Say something like, *It says here that personal vehicles that run on hydrogen use something called a fuel cell. I did some research on these, and they are somewhat similar to batteries.*

Display **slide C** and distribute copies of *Hydrogen Fuel Cells* and *Comparing Different Batteries* to each pair of students. Ask students to work with a partner to compare the hydrogen fuel cell design on *Hydrogen Fuel Cells* to the battery designs found on *Comparing Different Batteries*. Give partners a couple of minutes to stop and jot in their science notebooks the similarities and differences between the designs.

Discuss similarities and differences as a class. Present **slide D** and ask a few pairs of students to share some of the similarities and differences that they observed.

Suggested prompts	Sample student responses	Follow-up questions
What similarities did you observe between the hydrogen fuel cell and batteries?	Both have anodes and cathodes. Electrons flow from the anode to the cathode. Both also have an electrolyte.	*Are they made of the same materials?* *Are electrons the only things that move or flow?*

Suggested prompts	Sample student responses	Follow-up questions
What differences did you observe?	In the fuel cell, only positive ions flow through the electrolyte. The batteries are basically closed systems–there are no inputs or outputs except the electrons that flow between electrodes. The fuel cell has inputs–hydrogen and air–and outputs–excess fuel, unused gasses, and water.	*Why is that?* *What other systems have we looked at with fuel inputs and outputs?*

Highlight that fuel cells look like batteries and work similarly but have more obvious inputs and outputs, like gasoline-powered engines.

ALTERNATE ACTIVITY

If students want more information about how fuel cells work, suggest watching a video. **Slide E** demonstrates a homemade hydrogen fuel cell being charged and then used. **Slide F** provides an opportunity to share additional similarities and differences between batteries and fuel cells.

Say, *OK, I hear you saying that there are a lot of similarities between batteries and hydrogen fuel cells, but there are also some pretty big differences. To provide the steady energy needed to operate a vehicle, a fuel cell needs a continuous supply of hydrogen and oxygen. In a vehicle, oxygen comes from the air and hydrogen is stored in tanks.*

Ask, *Where do you think all that hydrogen comes from?* Accept all responses and suggest that if we want to evaluate hydrogen as a fuel like we have others, we probably need to better understand how it is obtained.

ALTERNATE ACTIVITY

Extension opportunity: One feature of hydrogen fuel cells that is blackboxed in this lesson is that the cathode and anode are both made of platinum, which serves as a *catalyst* for the electrolysis reaction. If you wish to explore catalysts, problematize that the anode and cathode are made of the same material. Elicit students' ideas about why they might be necessary for the reaction, and leverage their suggestions to lead students to the idea that they might somehow alter the energy required for the reaction so that it can take place more easily. Help students analyze energy coordinate diagrams for reactions with catalysts and compare with the graphs students used in Lessons 4-8. Then the need for platinum, which is very expensive, can be added to criteria and constraints in the next activity.

3 · HYDROGEN PRODUCTION

5 min

MATERIALS: science notebook

Consider hydrogen production from a criteria and constraints perspective. Show **slide G** and say, *Although hydrogen is the most abundant element in the universe, the molecule H_2 is only present in trace amounts in Earth's atmosphere, so if we are going to rely on hydrogen fuel cells for transportation, we will need to use chemistry to obtain H_2 from other substances that have it.* Give students a couple of minutes to read the slide and jot in their science notebooks about how these methods measure up to our criteria and constraints.

Discuss criteria and constraints as a class. Use the prompt to debrief as a class. Look for students to bring up pros and cons for both the reactants (fossil fuels and water) and the emissions (carbon dioxide and oxygen).

Suggested prompts	Sample student responses	Follow-up questions
How do these methods measure up to our criteria and constraints?	Almost all of the hydrogen produced is from fossil fuels that are not renewable. And getting hydrogen from fossil fuels also generates carbon dioxide, so that is no good. If hydrogen is made from water, the only other product is oxygen, which we need to breathe!	*Say more about why renewable is important to us. What does renewable really mean?* *What about producing hydrogen from water?* *Is it as beneficial if the hydrogen is made from methane?* *Where does the electricity come from to make hydrogen from water? Does it matter?*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students analyze the data on **slide G** to identify hydrogen production from fossil fuels as a source of carbon dioxide emissions (a greenhouse gas) in conflict with our criterion of lowest carbon dioxide emissions possible. (SEP: 4.5; DCI: ESS3.C.2, ETS1.A.1)
- Students analyze the data on **slide G** to identify hydrogen production from water as a source of oxygen emissions, which satisfies our criterion of low emissions from other pollutants. (SEP: 4.5; DCI: ESS3.C.2, ETS1.A.1)

What to do: Help students identify where in the life cycle the atmosphere is affected. If students struggle to see the distinction between the emissions generated when hydrogen is used as a fuel in a fuel cell and those generated during the production of hydrogen, consider charting out on paper the relationships between the steps.

Building toward 10.A.1 Analyze data about greenhouse gasses from hydrogen production and evaluate their impact on the transportation system to optimize it relative to criteria of greenhouse gas emissions to preclude ecosystem degradation. (SEP: 4.5, 4.6; CCC: 2.3; DCI: ESS3.C.2, ETS1.A.1)

4 · ANALYZE AND INTERPRET ATMOSPHERIC GAS DATA

14 min

MATERIALS: *Atmosphere Gas Data*, science notebook

Revisit carbon dioxide as a greenhouse gas. Summarize where the class is at. Say, *As a fuel in a fuel cell, hydrogen looks pretty good. It has a higher energy released than batteries, and the only emission from fuel cells is water. However, when we dig into how hydrogen is produced, we uncover CO_2 emissions—a greenhouse gas. What do we know about CO_2 as a greenhouse gas from prior units?* Display **slide H** and invite students to share ideas. Listen for the following ideas from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*:

- CO_2 heats up more than air under a light.
- The amount of CO_2 in the atmosphere is increasing.
- CO_2 stays in the atmosphere for a long time.
- CO_2 lets visible light through but absorbs infrared light.

Problematize greenhouse gasses. Suggest revisiting the natural gas/methane fuel card since it emits carbon dioxide when being used in hydrogen production. Show **slide I** and give students a minute to review the natural gas fuel card. Invite them to share any new things they notice or wonder and problematize greenhouse gasses by building onto their ideas as suggested below.

Suggested prompts	Sample student responses	Follow-up questions
What do you notice about methane?	It's also a greenhouse gas!	*Are there other greenhouse gasses?*
	Methane is a stronger greenhouse gas than carbon dioxide.	*What do you think makes methane a stronger greenhouse gas?*
	Methane leaks are possible during its extraction, transportation, and production.	*Why are leaks during methane's life cycle important to consider?*
What are you wondering about?	What makes something a greenhouse gas?	*What could we do to figure this out?*
	Why are some greenhouse gasses stronger than others?	*What kind of data should we look at?*

Analyze and interpret data for gasses in Earth's atmosphere. Display **slide J** and hand out a copy of *Atmosphere Gas Data* to each student. Ask students to work with a partner to analyze and interpret the data provided using the prompts on the slide. Give students 6 minutes to work.

Discuss the data as a class. Show **slide K** and use the prompts on the slide to facilitate a brief discussion. The data table from *Atmosphere Gas Data* is also shown on **slide L** for reference, as needed.

Suggested prompts	Sample student responses	Follow-up questions
Which gasses are NOT greenhouse gasses? Why?	Nitrogen, oxygen, and argon are not greenhouse gasses because they have GWP-100 values of zero.	*What does that mean?*
	Those gasses do not absorb light that is re-emitted by Earth. They let it pass through the atmosphere and out to space.	*What is your evidence?*
Which gasses are greenhouse gasses? Why?	The ones that warm the Earth as much as or more than carbon dioxide: methane and to a lesser degree, water.	*What type of data tells us that?*
	They absorb the infrared radiation emitted by the Earth, like water, carbon dioxide, and methane do.	*Is that the only thing that matters?*
	They also have to remain in the atmosphere for a while, like for 10-1,000 years.	*Does that account for the difference in GWP-100 for carbon dioxide and methane?*
	The amount of the gas that absorbs the light emitted by Earth is probably important too. If there is more of it, it will absorb more light (energy).	*What happens to these gasses when they absorb infrared light (energy)?*

Suggested prompts	Sample student responses	Follow-up questions
What affects the strength of a greenhouse gas?	Maybe the number of atoms and the type of atoms in a gas molecule? Gasses with one atom or two of the same atom have a GWP-100 equal to zero. Methane has the most atoms and the highest GWP-100.	*Why might that be important? What about water and carbon dioxide? Both have three atoms but different GWP-100.*
	It's a balance between how much infrared it absorbs and its lifetime in the atmosphere. Water absorbs a lot but has a short lifetime, so it has a low GWP-100.	*Does that explain the GWP-100 differences between water and carbon dioxide?*
	Yes, there is less carbon dioxide in the atmosphere, so it absorbs less energy, but it stays around for a long time.	*Does that explain the GWP-100 differences between carbon dioxide and methane?*

Summarize the discussion. Say something like, *OK, so the amount of infrared radiation that a gas can trap in Earth's atmosphere depends on lots of factors.* Highlight that we do not really have a good explanation for why some gasses absorb infrared light and others do not, but we did notice a pattern in the number of atoms in greenhouse gasses compared to other gasses.

5 · EXPLORE MOLECULAR VIBRATION

7 min

MATERIALS: science notebook, Set of gas molecule models

ADDITIONAL GUIDANCE

See *Assembling Molecular Models* for directions on making the set of gas molecule models. You could also distribute the materials and copies of *Assembling Molecular Models* to your first class of the day and instruct them to build the set of gas molecule models.

Identify next steps. Present **slide M** and suggest that it might be useful to examine some molecular models to see what happens to the bonds in gas molecules when they absorb infrared light. Discuss what we might see with those models.✱

Suggested prompts	Sample student responses	Follow-up questions
What happens to a molecule of greenhouse gas when it absorbs energy from infrared light?	It gets hotter.	*When the temperature increases, what does the molecule do?*
	It speeds up.	*We added energy to a system and broke bonds in Lesson 4. Why don't the bonds break in greenhouse gasses when they absorb this energy?*
How could we show that happening in greenhouse gas molecules compared to other molecules?	We could compare molecules with no GWP-100 to those with a high one.	*How could we model the speeding up or vibration of greenhouse gasses compared to other gasses?*
	We could look at actual molecules that vibrate.	

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Although not assessed, students' upcoming use of models is an important three-dimensional moment. Students are *using a model* to draw out *patterns* and demonstrate abstract ideas about *energy transfer* that have important implications for *environmental degradation.* Point out to students that they are using modeling and the lens of energy and matter in order to more fully explain why greenhouse gasses cause climate change.

If students do not suggest physical models, point out that if we think some molecules speed up or vibrate more than others, it might be useful to try to make that happen.

Explore molecular vibration with molecular models. Present **slide N** and review the directions on the slide. Distribute a set of gas molecule models to each group of five students and give them a few minutes to investigate the models.

Discuss patterns in molecular vibration. Show **slide O** and invite groups to share the patterns they observed in the ability of the different gas molecules to vibrate. **Slide P** is available if you wish to readily show different models to students and point to key features.

Suggested prompt	Sample student response
What patterns in molecular vibrations did you observe across molecules? Which molecule vibrates the least and why?	Nitrogen and oxygen vibrate the least, probably because they are only two atoms and the atoms are connected by a triple and double bond.
Which molecule vibrates the most?	Methane vibrates the most because it has four single-bonded hydrogens from the central carbon atom. Since methane has the most atoms, it has lots of ways to vibrate.
How did energy connect with vibration? What does this mean for greenhouse gas strength?	We had to put energy in to make the molecules vibrate. Greenhouse gasses must be the ones that don't have to have that much energy absorbed before they start vibrating a lot.
Why don't the bonds in greenhouse gasses break when they absorb energy?	There must not be enough energy added.

Motivate a return to engineering thinking. Point out that we now know that it is a lot better if we can avoid greenhouse gasses like methane when producing hydrogen because they cause significant problems. Suggest that we incorporate avoiding extra-strong greenhouse gasses into our criteria and constraints.

6 · REVISIT CRITERIA AND CONSTRAINTS

7 min

MATERIALS: science notebook, *Fuel Energy Released*, *Progress Tracker* from Lesson 2, internet-connected device, https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY, https://chargehub.com/en/charging-stations-map.html, "Criteria and Constraints" poster from Lesson 1, chart paper markers

Revisit our criteria and constraints. Direct students' attention to the "Criteria and Constraints" poster from Lesson 1 and show **slide Q**. Read through criteria and constraints and ask students how we should update the poster based on what we figured out about greenhouse gasses. If needed, point to the statement about CO_2 emissions and ask, *Is it just CO_2 emissions that we need to worry about?* Work with student ideas to update the poster to reflect the need for the "Lowest greenhouse gas emissions possible." Have students record additions on *Progress Tracker* from Lesson 2.

Identify additional possible constraints for using batteries and hydrogen fuel. Say, *Using hydrogen, especially if it is made from water, sounds pretty good. So why don't you think more vehicles have hydrogen fuel cells now? Or use batteries?* Present **slide R** and ask students to take a moment to consider the availability of different refueling options.

- *How far do you need to travel to refuel a vehicle with a carbon-based fuel, like gasoline, diesel, or biodiesel?*
- *Where do you need to travel to recharge a vehicle's battery or refuel a hydrogen vehicle?* (If a student says they can charge an electric vehicle at home, elicit suggestions about where this can be done when home is not an option.)

Accept all answers. Students will likely indicate that refueling options for carbon-based fuels are close by, while their responses for recharging batteries or refueling hydrogen will vary based on where you live.

Present **slide S**. Say, *Let's figure out just how many of these stations are available to us right now, as it might give us some ideas about new criteria we need to consider for designing our next generation of vehicles and the infrastructure we might need to support that.* Read through the directions on the slide. Give groups about 4 minutes to work on internet-connected devices to divvy up the exploration of the two websites:

- https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY
- https://chargehub.com/en/charging-stations-map.html

Use the following prompts to elicit groups' findings.

Suggested prompt	Sample student response
How many hydrogen fuel stations are available in our area?	Answers will vary depending on the location of your school.
How many battery recharging stations are available in our area?	Answers will vary depending on the location of your school.
Based on this information, how might it help explain why more people are not using electric or hydrogen fuel cell vehicles right now?	Answers will vary depending on location. There are not enough places to recharge batteries or refuel hydrogen fuel cell vehicles.
How could we change this in the future?	Build more recharging/refueling stations!

ALTERNATE ACTIVITY

If students are interested in getting a national picture, encourage them to explore recharging and refueling options on this larger scale. Students should come to the same conclusions but may point out that some areas have better infrastructure to support the use of battery-powered or hydrogen fuel cell vehicles than others.

7 · NAVIGATE

5 min

MATERIALS: science notebook, *Progress Tracker* from Lesson 2

Update Progress Trackers. Present **slide T**. Say, *We have figured out a lot about how hydrogen could be used as a fuel in a fuel cell. We also started to think about where that hydrogen fuel would come from and potential issues associated with its production. Along the way, we deepened our understanding of greenhouse gasses. Wow! We have really figured out a lot! Take a moment to work with a partner to update your Progress Tracker with this new information. Use the prompts on the slide to help you think about this entry.*

See below for a sample Progress Tracker update. Ensure students add to their criteria and constraints lists as needed.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	Engineering implications Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
Hydrogen fuel cells are similar to batteries in that they directly produce electricity and similar to engines in that they have inputs (hydrogen and oxygen) and outputs (water). Although they do not produce carbon dioxide, it is a by-product of producing hydrogen from natural gas (methane). Methane and carbon dioxide are greenhouse gasses (GHGs) because they persist in the atmosphere and absorb infrared radiation emitted by the Earth. Compared to non-GHGs, the atoms in methane and carbon dioxide are more able to vibrate. Methane vibrates more than carbon dioxide, and it warms the atmosphere ~30 times more than the same amount of carbon dioxide over 100 years.	*In a fuel cell, it reacts with oxygen in the air to produce water as the only emission.* *However, almost all of the hydrogen produced today comes from methane (a greenhouse gas prone to leaks) and carbon dioxide is produced as a by-product.* *Fuel cells would probably not be compatible with existing vehicles because hydrogen is a gas, not a liquid like current fuels.* *Hydrogen filling stations are currently more rare than charging stations.*	Avoid: *Producing hydrogen from reactants that produce carbon dioxide as a by-product or are GHGs themselves and may contribute to emissions .* Shift: *Produce more hydrogen from water using renewable sources of electricity. Provide more hydrogen refueling stations.* Improve: *Methods to produce hydrogen that do not also emit GHGs.*

ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment:

- Students cite carbon dioxide (a greenhouse gas) produced during the transformation of fossil fuels into hydrogen gas as being in conflict with the criterion of a transportation system with low carbon dioxide emissions. (DCI: ESS3.C.2, ETS1.A.1; CCC: 2.3)
- Students cite methane, the main fossil fuel used to produce hydrogen, and the potential for leaks during its lifecycle as being in conflict with the criterion of a transportation system with low other pollutants. (DCI: ESS3.C.2, ETS1.A.1; CCC: 2.3)
- Students include engineering implications that cite the need to lower the greenhouse gas emissions associated with hydrogen production for a viable next generation transportation system using hydrogen as a fuel. (DCI: ESS3.C.2, ETS1.A.1; CCC: 2.3)
- Students tie data about fueling options and greenhouse gasses to criteria and constraints on a transportation system. (SEP: 4.6)

What to do: If students do not include engineering implications, prompt them to consider the second prompt on **slide T**, "Why does it matter what methods we use to produce hydrogen fuel?" If they do not leverage data to share these implications, elicit suggestions about the different data sources we analyzed and what each one tells us about science ideas or engineering implications for the transportation system.

Building toward 10.A.2 Analyze data about greenhouse gasses from hydrogen production and evaluate their impact on the transportation system to optimize it relative to criteria of greenhouse gas emissions to preclude ecosystem degradation. (SEP: 4.5, 4.6; CCC: 2.3; DCI: ESS3.C.2)

Navigate to the next lesson. Present **slide U**. Ask, *What other non-carbon-based fuel source were we wondering about?* Look for students to say uranium. Say, *Let's look at that next class!*

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Students translate information expressed visually in *Hydrogen Fuel Cells* and *Comparing Different Batteries* into words when they jot similarities and differences between hydrogen fuel cells and batteries in their science notebooks and discuss them with their class. They also do this when they work with a partner to analyze and interpret the data in *Atmosphere Gas Data* and discuss it with their class.

LESSON 11: Where is the energy coming from when we use uranium as a fuel?

PREVIOUS LESSON

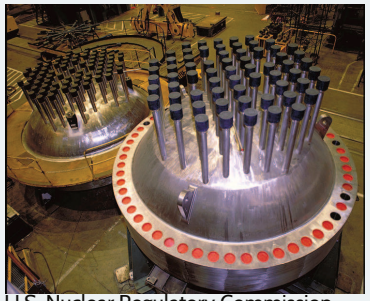
We identified similarities between hydrogen fuel cells and batteries and engines. We examined data on global hydrogen production and analyzed and interpreted gas data and molecular models to understand greenhouse gasses. We revisited our criteria and constraints and updated our Progress Trackers.

THIS LESSON

INVESTIGATION, PROBLEMATIZING

3 days





U.S. Nuclear Regulatory Commission

We have not explained how uranium fuel works yet and analyze the structure of a nuclear reactor. We apply M-E-F lenses to nuclear fission. We recognize that forces must be at work and realize that protons and neutrons must be important to these forces. We analyze data on protons and neutrons and read about the strong nuclear force. Given the large amount of energy transferred out of nuclear fission, we are surprised that it is not more common as a fuel source. We jigsaw articles that describe different concerns with using uranium as fuel, update our Progress Trackers, and complete an Electronic Exit Ticket.

NEXT LESSON

We will examine the environmental impact from the increase in space flights leaving Earth's atmosphere. We will develop criteria and constraints for choosing a rocket fuel and use an article comparing chemical and nuclear rockets to refine our class list. We will argue individually for which, or neither, fuel should be used in future space missions.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1



WHAT STUDENTS WILL DO

11.A Construct an explanation based on a variety of sources using structure-function relationships to show how protons and neutrons are conserved during nuclear fission while energy is released. (SEP: 6.2; DCI: PS1.C.1; CCC: 6.1, 5.5)

11.B Evaluate the impact of new data related to nucleus structures on the model of energy transfer in and out of fields during nuclear fission. (SEP: 4.5; DCI: PS3.C.1, PS1.C.1; CCC: 6.1)

11.C Apply scientific ideas, principles, and evidence to identify unanticipated effects of a transportation design solution that may result in problems in the system due to associated costs and risks. (SEP: 6.3; DCI: ESS3.A.2; CCC: 2.3)

WHAT STUDENTS WILL FIGURE OUT

- In nuclear fission, neutrons and protons are conserved, but atoms can change into different elements as large nuclei split.
- We would expect protons to repel due to electrostatic forces, but when there are the right ratios of protons and neutrons in a nucleus, the strong nuclear force is able to hold them together. This force only works on short ranges.
- Outside energy is required to break apart the "bonds" of the strong nuclear force.
- When protons and neutrons get just too far apart for the strong nuclear force to take hold, protons repel strongly due to the electrostatic force, and energy transfers from electric fields to the particles, causing a drastic increase in temperature.
- Various constraints around size, safety, cost, and environmental concerns have limited the use of uranium as a fuel, particularly in transportation.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Lead students in an opening discussion about how uranium compares to the other fuels that have been examined.	A-B	
2	10 min	✓	**ANALYZE THE STRUCTURE OF A NUCLEAR REACTOR** Give students time to analyze and discuss the structure of a nuclear reactor.	C-D	*Submarine Nuclear Reactors*
3	14 min	✓	**EXPLORE THE REACTANTS AND PRODUCTS IN A NUCLEAR PROCESS** Lead whole-class discussions about the process of nuclear fission. Have students turn and talk with a partner to determine if matter is conserved during this process.	E-I	periodic table (wall or virtual)
4	6 min		**EXAMINE NUCLEAR FISSION WITH AN ENERGY LENS** Organize students into pairs to use a simulation in order to examine nuclear fission from an energy lens.	J	https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission, internet-connected device, projector with sound
5	10 min	✓	**LEAD A BUILDING UNDERSTANDINGS DISCUSSION** Lead a Building Understandings Discussion of the simulation results.	K-L	
					End of day 1
6	5 min		**NAVIGATE** Have students turn and talk with a partner to reflect on what we figured out last class.	M	
7	8 min		**ANALYZE DATA ON PROTONS AND NEUTRONS** Organize students into pairs to analyze CODAP data.	N	*Protons and Neutrons*, https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2F2YYLnPQmYFMS6euFAlfa%2Ffile.json, internet-connected device
8	10 min		**MAKE SENSE OF THE PROTON AND NEUTRON DATA** Lead a whole-class discussion to make sense of the CODAP data.	O	*Protons and Neutrons*
9	10 min		**READ ABOUT FORCES IN THE NUCLEUS** Have students read about strong nuclear force. Lead a class discussion to share similarities and differences between other forces we have previously studied.	P-Q	*Nuclear Force*
10	12 min	✓	**MAP TO THE SIMULATION** Display the simulation and use prompts to help students map different areas of the simulation to regions in which the electric or strong nuclear force dominates.	R	https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission, projector with sound, 3x3 sticky notes, colored markers, M-E-F poster (optional)

Part	Duration		Summary	Slide	Materials
					End of day 2
11	4 min		**NAVIGATE** Have students stop and jot in their notebooks to consider where energy comes from when uranium is used as fuel.	S	
12	5 min		**COMPARE ENERGY RELEASED VALUES** Organize students into small groups to compare released values of other fuels with the fuel data cards. Lead a class discussion to share differences.	T-U	Fuel Data Cards from Lesson 1
13	20 min		**READ ABOUT DIFFERENT ASPECTS OF NUCLEAR FISSION USE FOR TRANSPORTATION AND ELECTRICITY** Organize students into groups of 4 to jigsaw readings about different aspects of the nuclear fission process.	V-X	*Safety: Control Rods*, *Environment: Nuclear Waste*, *Safety: Supply Chain*, *Infrastructure: Nuclear Plants*
14	8 min		**ADD TO PROGRESS TRACKERS** Discuss new engineering ideas as a class before updating the Progress Tracker.	Y-Z	*Progress Tracker* from Lesson 2
15	8 min		**COMPLETE AN ELECTRONIC EXIT TICKET** Have students complete an Electronic Exit Ticket.	AA	Electronic Exit Ticket, internet-connected device, *Electronic Exit Tickets* from Lesson 5
					End of day 3

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Submarine Nuclear Reactors* • *Protons and Neutrons* • *Nuclear Force* • *Progress Tracker* from Lesson 2 • Electronic Exit Ticket • internet-connected device	• https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission • internet-connected device • https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2F2YYLnPQmYFMS6euFAIfa%2Ffile.json • Fuel Data Cards from Lesson 1 • *Safety: Control Rods* • *Environment: Nuclear Waste* • *Safety: Supply Chain* • *Infrastructure: Nuclear Plants*	• periodic table (wall or virtual) • https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission • projector with sound • 3x3 sticky notes • colored markers • M-E-F poster (optional) • *Electronic Exit Tickets* from Lesson 5

Materials preparation (40 minutes)

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

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

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

Familiarize yourself with https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission and the data set at https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2F2YYLnPQmYFMS6euFAIfa%2Ffile.json.

Review *Simulation Mapping* to familiarize yourself with how energy in nuclear fission will be discussed in this lesson and how it differs from typical representations.

Have the M-E-F poster available for day 2.

Have the Fuel Data Cards from Lesson 1 ready to use on day 3.

Ensure that enough copies of each of the following readings are available so that one student in each group of four can access one:

- *Safety: Control Rods*
- *Environment: Nuclear Waste*
- *Safety: Supply Chain*
- *Infrastructure: Nuclear Plants*

Create Electronic Exit Ticket forms for this lesson using the directions found on *Electronic Exit Tickets* from Lesson 5.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.C.1 Nuclear Processes:** Nuclear processes, including ~~fusion,~~ fission, ~~and radioactive decays of unstable nuclei,~~ involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.
- **PS3.C.1 Relationship Between Energy and Forces**: When two objects interacting through a field change relative position, the energy stored in the field is changed.
- **ESS3.A.2 Natural Resources**: All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. ~~New technologies and social regulations can change the balance of these factors.~~

Crossout explanation: This lesson will not address the processes of nuclear fusion or radioactive decay. Radioactive decay will be addressed in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* and nuclear fusion in *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*. This lesson will also not consider why radiation might be considered unsafe. Students grapple with this idea in *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*. Students will consider how new technologies and social regulations can change the balance of factors in Lesson Set 3.

This lesson should encourage students to begin to think about the implications of the following disciplinary core idea around widespread use of fuels that are not carbon-based:

- **ESS3.A.1 Natural Resources:** Resource availability has guided the development of human society.

This disciplinary core idea will be fully addressed in Lesson Set 3.

This lesson will build these ideas in part by leveraging the understanding of subatomic structure, in particular the nature of the nucleus and role of forces in mediating particle behavior developed in *Electrostatics Unit* and *Space Survival Unit*. This lesson helps students map their current model of energy transfer in chemical reactions to the process of nuclear fission. There are significant differences between these processes. First, in nuclear fission, protons and neutrons are conserved, but atoms are not. Second, the amounts of energy transferred in nuclear fission are significantly greater than in chemical reactions (as evidenced by the high energy released by uranium). Third, the strong nuclear force and electrostatic force both play an important role in nuclear fission. In nuclear fission, an initial input of energy (typically a neutron hitting a nucleus) causes the nucleus to become unstable. This energy, transferred to the fields between protons and neutrons, can provide enough energy that the strong nuclear force can no longer hold the nucleus together. Then immensely strong electrostatic forces cause the protons to repel, transferring energy from the electric fields between protons to the particles themselves.

Students *construct an explanation* from their energy transfer models and in-lesson sources to explain the source of the energy in nuclear fission (SEP: 6.2). This requires *analysis of the structures* in a nuclear reactor and explicit consolidation of *particle-level conservation in nuclear processes* (CCC: 6.1, 5.5). On day 2, students consider how new data about the different isotopes *impacts their working explanation* (SEP: 4.5). This requires students to consider *nucleus-scale components and interactions* (CCC: 6.1). On day 3, students *apply their ideas and evidence* from readings to begin to *solve a design problem* around why nuclear cars and trucks do not exist, taking into consideration the risks and costs of using nuclear fission for energy (SEP: 6.3; CCC: 2.3)

The lesson uses the familiar terms "reactants" and "products" to describe the different components in nuclear processes and the more traditional terms of parent nucleus and daughter nuclei are not used (except in the simulation). This emphasizes that nuclear processes involve changes in matter. However, we will carefully call nuclear fission a "process" rather than a "reaction" to distinguish it from chemical reactions.

In this lesson, students will co-construct a definition for the following words, which they should add to their Personal Glossaries: *nuclear fission* and *isotopes*. They may also wish to add definitions for other words encountered in this lesson, such as *chain reaction*, *nuclear waste*, and *nuclear reactor*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

This lesson will not address mass-energy equivalence or its related equation $E = mc^2$. This relationship is typically used to explain the energy released from nuclear processes, but if not done with nuance, it can obscure the underlying mechanisms. For more information on how to discuss the energy transfer out of a nuclear process, see *Simulation Mapping*. Students are also not introduced to the term "nuclear binding energy," as they do not do calculations using the energy inputs and outputs in nuclear fission. Students do not explain why strong force does not cause the nucleus to collapse in on itself, as this relies on quantum effects that are outside the scope of the NGSS.

Students do not consider material properties as they relate to function in this lesson, as this was an emphasis in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

5 min

MATERIALS: None

Navigate. Display **slide A** and read the question aloud: *One fuel we have not considered is uranium. How does it compare to other fuels?* Give students a minute to think about what they already know about uranium.

Display **slide B.** Have students discuss the questions on the slide with a partner for three minutes, and then discuss these questions as a class.

Suggested prompt	Sample student response
How does uranium compare to other fuels?	It produces a LOT more energy than other fuels. It has a higher energy released than other fuels. It produces no carbon dioxide emissions. The fuel card says it is mainly used in subs and big ships. It is radioactive.
What else do you know about uranium as a fuel?	Accept all responses.
What are we wondering?	Why does it provide so much more energy than other fuels? Why don't we use it in smaller vehicles? What sort of waste products does it produce? How long are the waste products radioactive for?

Suggest that since we have all of these questions related to this fuel, we should start investigating them in a manner similar to how we started our investigations of other fuels, by first analyzing diagrams of the parts in the systems that are used to harness energy from the fuel to make a vehicle move.

2 · ANALYZE THE STRUCTURE OF A NUCLEAR REACTOR

10 min

MATERIALS: science notebook, *Submarine Nuclear Reactors*

Analyze the structure of a submarine nuclear reactor. Display **slide C.** Cue students to create a Notice and Wonder chart in their notebooks as you distribute a copy of *Submarine Nuclear Reactors*. Give students four to five minutes to analyze the diagram with a partner.✱

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: *Submarine Nuclear Reactors* is fairly dense. Consider showing https://www.youtube.com/watch?v=vlsqxh3eyo8 before students engage with the reading to support emergent multilinguals and other students.

ADDITIONAL GUIDANCE

The "uranium" pellets pictured in *Submarine Nuclear Reactors* are actually uranium hexafluoride, UF_6. There are various technical reasons for the use of UF_6 pellets rather than pure uranium. The full explanation for this is outside the scope of this unit.

Display **slide D** and lead a discussion of the questions.

Suggested prompt	Sample student response
What structures did you notice in the reactor?	There's fuel. There are control rods, whatever those are. Both of these are in a "pressure vessel," but it doesn't appear to have a moving piston. It's larger than a combustion engine. There is no exhaust pipe. There are multiple water loops. The whole thing is very large.
Which parts or interactions made sense in terms of how they might work together to make the vehicle move?	The fuel heats up the water. The steam collides with blades on a shaft and spins the turbine. The turbine is connected (by gears and shafts) to a propeller, which is similar to how an engine turns a wheel. A neutron is added to the system, kind of like a spark is added with gasoline.
Which types of vehicles could effectively get energy from something the size of a nuclear reactor?	Only big ones. Ships and submarines. Would a really big truck be big enough? But then you wouldn't have space for other stuff.
What questions does this raise for us?	How does uranium cause water to heat up? What does the control rod(s) do? Is uranium reacting with the air or with something else? Why are there multiple water loops?

Motivate exploring the system from a matter perspective. Say, *With other fuels, we looked at the reactants and products, as we focused on the matter changes happening in the system, to try to figure out answers to some of our questions. Let's see if starting with that perspective helps us make sense of what is happening in this system too.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students should suggest initial explanations that use evidence from the diagram to identify structures and their connections and propose possible functions of the components. (SEP: 6.2; CCC: 6.1)

What to do: Put the diagram on screen if possible and encourage students to point to particular components and connections as evidence for their ideas about how the parts work together. Show https://www.youtube.com/watch?v=vlsqxh3eyo8 again if necessary. If you would like a chance to review each student's work, have them write a response in their science notebooks.

Building toward 11.A.1 Construct an explanation based on a variety of sources using structure-function relationships to show how protons and neutrons are conserved during nuclear fission while energy is released. (SEP: 6.2; DCI: PS1.C.1; CCC: 6.1, 5.5)

3 · EXPLORE THE REACTANTS AND PRODUCTS IN A NUCLEAR PROCESS

14 min

MATERIALS: science notebook, periodic table (wall or virtual)

Introduce isotope notation. Display **slide E.** Say, *You may have noticed a number symbol connected to uranium on its fuel card, a U with a little 235 next to it. Scientists use this numerical notation to indicate different versions of the same element. For example, uranium has different versions, including uranium-235 and uranium-238.* Lead a discussion about what this notation might mean.✱

Suggested prompt	Sample student response
What do we know about the subatomic particles in these atoms?	There are protons and neutrons in the nucleus. There are electrons outside the nucleus.
In what ways would these neutral uranium atoms have to be the same?	If they are neutral, they have to have the same number of electrons as protons. They have to have the same number of protons as each other because they are both uranium. If they had a different number of protons, they would be something else.
How could they be different?	They cannot have different numbers of protons or electrons. Maybe the particles are arranged somewhat differently? They could have different numbers of neutrons.✱

ALTERNATE ACTIVITY

Building prerequisite understandings: Students learned about neutrons in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. Students may have had questions in that unit about the role neutrons play, but they have not been a key part of students' explanations and models since then. If students do not remember neutrons, use a simulation such as https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_all.html to remind students about the different subatomic particles in an atom and their properties.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Students may or may not mathematically determine matter conservation by counting mass in the reactants and products. If students are still unsure, have students that did mathematically determine matter conservation share how they did it with the class. This helps support students' engagement with *representation* as classmates explain how to use the symbols in the table on **slide F** to support that matter is conserved.

✱ SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Later, when students think more deeply about nuclear "reactions," encourage students to reflect on whether these nuclear processes have always operated this way. Remind them that in science, we generally assume that once we have developed a theory or law based on evidence, we assume it works throughout time until we observe contrary evidence.

Display the periodic table and point out to students that the numbers 235 and 238 are near the atomic mass shown on the periodic table (238.03). Follow up by asking, *Which particles contribute to atomic mass?* Students may recall that protons and neutrons contribute to mass; if not, remind them. Present this as evidence that these numbers represent the mass of the atom and include the number of protons as well as neutrons.

Name these different variations as *isotopes*. Highlight that isotopes of an element are the same other than their atomic mass/number of neutrons, just like ions of an element are the same except for their charge/number of electrons.

Explore the reactants and products related to using uranium-235. Display **slide F.** Cue students to consider how the reactants and the products compare when uranium-235 is used as a fuel. Have students discuss the two questions on the slide with a partner and then discuss these as a class.

Suggested prompt	Sample student response
How is this process similar to or different from chemical reactions we have seen?	All the types and number of particles that make up the starting nucleus can be accounted for (matter is conserved). New types of atoms are made from old types of atoms. There are neutrons in the reactants and products. There are more neutrons in the products than in the reactants.
Is matter conserved? How do we know?	No, because the uranium atom from the beginning is not there at the end. Yes. The total number of protons and neutrons in the reactants is 236. This is the same in the products.

Summarize the discussion and highlight how uranium is different from chemical reactions. Say, *Even though matter is conserved in this reaction, notice that the types of atoms are different. Because of this, we cannot consider this to be a chemical reaction. It is considered a nuclear process because the nucleus is different in each product atom compared to the reactant atoms.*

ADDITIONAL GUIDANCE

Students may ask why these particular elemental products result from this nuclear process (a fission process, as it will be named shortly). If they do, share that there would actually be a range of different, smaller atoms as products. Do not bring this detail up unless in response to student needs.

Compare uranium's fission to other nuclear processes. Say, *Though uranium-235 is the most commonly used nuclear fuel, there are other types of atoms that can be used as fuels in nuclear reactors. Let's take a look at how the matter changes in those reactions.* Display **slide G.** Give students 3 minutes to examine the reactions on **slide G** and turn and talk with a partner about the prompts. Then discuss them as a class.

Suggested prompt	Sample student response
What do you notice about these processes? What do they have in common?	The total number of protons and neutrons in the reactants is equal to the total number in the products. They all have 1 neutron in the reactants. They all produce three neutrons in the products. They all have a larger nucleus atom in the reactants.
How can there be new elements in the products? Where is the matter for these coming from?	The big atom would have to be breaking up into smaller atoms. The matter comes from the reactants.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should explain that matter is conserved because the number of protons and neutrons is constant. (SEP: 6.2; CCC: 5.5)
- Students should use evidence from the nuclear "equations." (SEP: 6.2; DCI: PS1.C.1)

What to do: This moment represents a paradigm shift in conservation of matter from the atomic level to the subatomic level. Leverage students' experience with stoichiometry and encourage them to think in terms of atomic mass. Ask, *As far as we can tell, will the atomic mass of the reactants and products be the same? If so, then matter must be conserved.*

Building toward 11.A.2 Construct an explanation based on a variety of sources using structure-function relationships to show how protons and neutrons are conserved during nuclear fission while energy is released. (SEP: 6.2; DCI: PS1.C.1; CCC: 6.1, 5.5)

Shift lenses. Display **slide H** and name this process as *nuclear fission*. Briefly discuss the statement about the origins of the name *fission* as well as the prompt on the slide. Students may share any of these ideas:

- *Yes, because we are still working with atoms.*
- *No, because the atoms/nuclei are breaking apart in ways they did not in prior lessons or units.*

ALTERNATE ACTIVITY

Extension opportunity: Lise Meitner (pronounced "Leez MITE-ner") and Otto Frisch discovered nuclear fission while discussing some results from another scientist, Otto Hahn, who had encountered results he could not explain. While Hahn won the 1944 Nobel Prize in Chemistry, Meitner never received formal credit for her role. Direct students to https://www.aps.org/publications/apsnews/200712/physicshistory.cfm for more information about Meitner's story, including her flight from Nazi-controlled Austria. (SEP: 8)

Update Personal Glossaries. Present **slide I**. Give students a moment to update their Personal Glossaries with *nuclear fission*, *isotopes*, and any other words you wish to highlight. Encourage students to illustrate these abstract definitions so that they are multimodal.

4 · EXAMINE NUCLEAR FISSION WITH AN ENERGY LENS

6 min

MATERIALS: science notebook, https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission, internet-connected device, projector with sound

Introduce the simulation.✱ Say, *In previous lessons, we used matter, energy, and force lenses to explore fuel phenomena. We just looked at matter,*

✱ **ATTENDING TO EQUITY**

so now let's look at what is happening during nuclear fission from an energy lens. Display **slide J**. Show students how to use the first tab of the simulation. Focus on how to launch a neutron at the nucleus and reset it when done. Additionally:

- Point out that the graph shows the potential energy (which we call energy stored in fields) and total energy in the system.
- Identify "daughter nuclei" as describing the fission products.

Provide time to engage with the simulation. Have students make a Notice and Wonder chart in their science notebooks. Give students time to make observations of the first tab of https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission in pairs.

ALTERNATE ACTIVITY

Extension opportunity: The second and third tabs introduce the idea of chain reactions and expand on the role of control rods in reactors respectively. Either or both could be used with a subset or all students after the jigsaw on day 3, which includes the reading *Safety: Control Rods*.

The term "daughter" nuclei is used in the simulation. However, "daughter nuclei" imprecisely ascribes human gender to the product nuclei of fission. The term "product" nuclei is preferable, as it is consistent with the language students have used throughout the OpenSciEd Chemistry course when describing chemical processes.

5 · LEAD A BUILDING UNDERSTANDINGS DISCUSSION

10 min

MATERIALS: None

Discuss the simulation results. Display **slide K** and use the prompts on the slide.✱

Suggested prompt	Sample student response
What did you notice in the simulation?	A neutron has to be shot at the atom. The atom is listed as uranium-235. It turns to uranium-236, wiggles, and pushes apart.✱ Energy is conserved because the total energy stays the same except when the neutron that is shot transfers in energy from the outside. Energy in the field (potential energy) of each of the particles decreases as they fly off.
How is nuclear fission like bonds breaking?	Energy is transferred into the system through a high-speed particle (neutron). The other particles rearrange or move around. There is an attraction. Another word for an attraction is a force.
How is nuclear fission different from bonds breaking?	Energy is transferred out. We aren't sure if this counts as a bond. We saw bonds breaking and nothing forming.

Transition to the role of forces. Say, *We have been comparing nuclear fission to bonds breaking. What do we need for there to be bonds between particles?* Listen for these ideas:

- There needs to be some sort of attraction between them.

✱ ATTENDING TO EQUITY

In order to promote epistemic justice, try to get multiple students to share ideas in a row before you chime in. One simple way to promote student-to-student sharing of ideas: stare at them. Actively make eye contact with a number of students until someone adds an idea. If students do not volunteer their ideas, ask, *Did everyone hear what __ said? Do you need them to repeat it so we can hear related ideas?*

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

It is important that students connect the "bonds" breaking to energy transfer into the system. Point out the "wobble" if it is not mentioned and ask students where we have seen this before. Use this to establish that *energy is transferred into the system* by the neutron. (CCC: 5.3)

- There need to be forces or fields.

Use the idea that what is going on in the nucleus is kind of like bonds. Display **slide L** and continue the discussion by problematizing the forces inside the nucleus.

Suggested prompt	Sample student response
What do we know about the forces at work between protons, neutrons, and electrons?	In chemical reactions, there are electrostatic forces between a nucleus and electrons. The simulation only includes protons and neutrons. Protons repel due to electrostatic forces. We do not know about any forces that could affect neutrons.
How do those forces work together to hold the nucleus and the atom as a whole together?	We don't know. There are only protons and neutrons, so any force must involve those particles.

Summarize that we are not sure about the role of forces. Say, *Maybe we need to think more about forces between protons and neutrons in the substances used in nuclear reactors.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should initially explain, using evidence from the simulation, equations, and diagram, how energy is released in nuclear fission. (SEP: 6.2; DCI: PS1.C.1)
- Students should articulate that the same particles rearrange in nuclear fission (matter is conserved). (CCC: 5.5)

What to do: If students do not connect energy transfer to changes in fields or "bonds" breaking and forming, point out that when the neutron is first shot at the nucleus, we observe a "wobble" much like that highlighted in Lesson 4. It is okay to leave it a mystery where exactly this energy is coming from, as long as students recognize that it must be related to the forces in the nucleus.

Building toward 11.A.3 Construct an explanation based on a variety of sources using structure-function relationships to show how protons and neutrons are conserved during nuclear fission while energy is released. (SEP: 6.2; DCI: PS1.C.1; CCC: 6.1, 5.5)

End of day 1

6 · NAVIGATE

5 min

MATERIALS: None

Navigate into protons and neutrons. Display **slide M**.

Suggested prompt	Sample student response
What did we figure out last class in terms of matter, energy, and forces?	We can account for the matter in fission. We see changes in energy in the field as well as energy input and output. We know of electrostatic forces, but these would repel in the nucleus.
What were we wondering or unsure of?	What other forces might be involved? What is holding the nucleus together when the protons should repel? What role do neutrons have?

Say, *It sounds like we have questions about what forces are there and that we think protons and neutrons are somehow involved in these forces. Let's dive into the nucleus and think about the numbers of protons and neutrons in different isotopes.*

7 · ANALYZE DATA ON PROTONS AND NEUTRONS

8 min

MATERIALS: *Protons and Neutrons*, https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2F2YYLnPQmYFMS6euFAIfa%2Ffile.json, internet-connected device

Introduce the data set. Display **slide N** and distribute *Protons and Neutrons*. Have them read the information at the top out loud with their partners before opening the CODAP.

Open CODAP. Open the CODAP on a projected display and walk students through the data set at https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2F2YYLnPQmYFMS6euFAIfa%2Ffile.json. Ask orienting questions such as, *What do you notice?* and *What can we learn from this data set?* Give them six to seven minutes to complete *Protons and Neutrons* with a partner. Tell students that the handout will ask them to change the chart using CODAP's drag and drop functionality and show them how to do so if necessary.

8 · MAKE SENSE OF THE PROTON AND NEUTRON DATA

10 min

MATERIALS: *Protons and Neutrons*

Discuss the proton and neutron data. Display **slide O**.

Suggested prompt	Sample student response
What patterns did we notice in the proton and neutron data?	Isotopes with bigger atomic numbers have more neutrons than protons. Lower-number isotopes have about the same numbers of protons and neutrons.

Suggested prompt	Sample student response
What patterns did we see when we graphed the number of protons or neutrons against stability, presence in nature, or use in fission?	Bigger isotopes tend to be less stable. Bigger-number isotopes are less likely to exist in nature. Only bigger isotopes are considered for use in fission. Not all of them exist in nature.
What do the patterns tell us about how the numbers of protons and neutrons influence the forces keeping the nucleus together?	Bigger isotopes tend to be unstable and break apart easily, so a lot of protons and neutrons must make it harder for a nucleus to hold together. Bigger isotopes need more neutrons than smaller isotopes to exist at all, so maybe neutrons play an important role in holding the nucleus together.
What specific force would neutrons be responding to? They do not have a charge, so it cannot be the electrostatic force.	Maybe the magnetic force? We are not sure. This is very different from what we have seen before.

ADDITIONAL GUIDANCE

It may be helpful to display https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2F2YYLnPQmYFMS6euFAIfa%2Ffile.json during this discussion if students are struggling to identify any of the patterns in the data.

Say, *This data seems to have given us more evidence that protons and neutrons are involved in holding the nucleus together, but we do not really know what force is involved. We probably need more information on that.*

9 · READ ABOUT FORCES IN THE NUCLEUS

10 min

MATERIALS: *Nuclear Force*, science notebook

Introduce the reading. Display **slide P**. Ask, *What forces do we already know about?* Students should identify the electrostatic force, the magnetic force, and maybe gravity. Distribute *Nuclear Force*. Tell students that as they read, they should record in their notebooks ways in which the force in the nucleus is similar to or or different from these forces.✱

ALTERNATE ACTIVITY

Extension opportunity: Some students may have heard about subatomic particles smaller than neutrons and protons or wonder how these particles are able to interact with each other when neutrons have no charge. Only if these questions come up, you may encourage students to obtain and evaluate information about the relationship between quarks and color charge (a rough analogue to electric charge) as they relate to the strong nuclear force. (SEP: 8)

Debrief the reading. Display **slide Q**.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Allow students to choose to read in a small group, with you, with a partner, or on their own. This kind of student-choice grouping acts as a support for *engagement* with the science and engineering practices of *working with information.*

Suggested prompt	Sample student response
How is the strong nuclear force similar to other forces?	It is attractive, like some other forces attract. The forces are connected with fields that store energy.
How is it different from other forces?	It is super strong and short-ranged. It is between any combination of protons and/or neutrons. Electrons do not "feel" the strong nuclear force. More energy is transferred out of the field during fission than during chemical reactions.

ADDITIONAL GUIDANCE Students may be surprised that electrons do not respond to or "feel" the strong nuclear force. Listen carefully for references to electrons or different particles and use these as opportunities to ask, *How do particles behave differently in the presence of the strong nuclear force compared to other forces?*

10 · MAP TO THE SIMULATION

12 min

MATERIALS: https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission, projector with sound, 3x3 sticky notes, colored markers, M-E-F poster (optional)

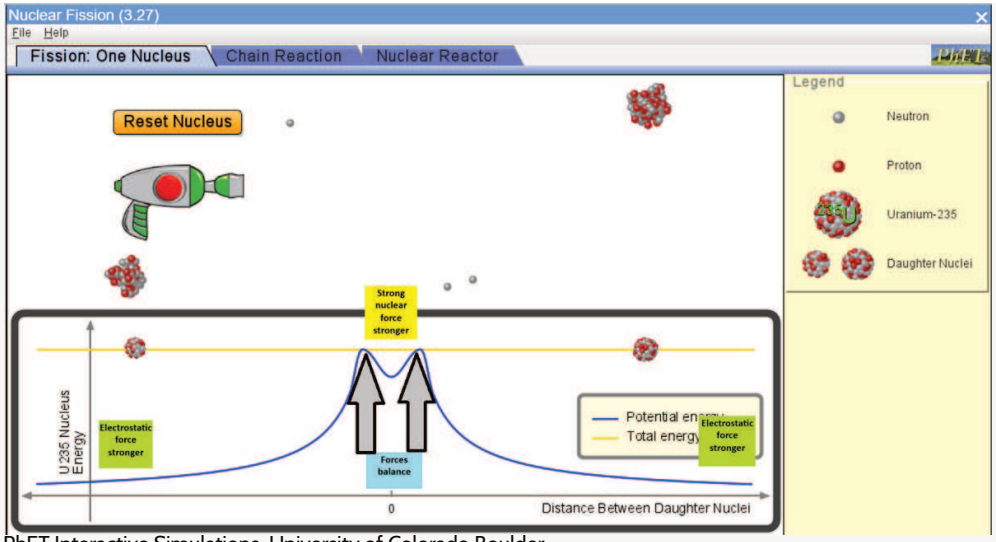
Map the reading to the simulation. Suggest that the reading might help us better understand the ideas in the simulation. Display https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission. If you have space, also display **slide R.✱**

Reset and show the simulation once to remind students of how actions correspond to different areas on the energy graph. Then use the prompts to map out different areas.

Suggested prompt	Sample student response
Where is each force stronger?	The strong nuclear force is strongest in the dip in the middle where the nucleus was wobbling. The electrostatic force is stronger out where the nuclei were repelling. Label these regions with a sticky note as shown below.
Where are they balanced?	The forces balance at the humps. Label this region with a sticky note as shown below.

✱ ATTENDING TO EQUITY

Ensure that student voices are front and center during this discussion. Instead of taking the first response, allow multiple students to share competing ideas, asking students to refer to the simulation and the reading as they share their ideas.



PhET Interactive Simulations, University of Colorado Boulder

Focus on the idea of energy in this central region. Keep projecting https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission and use the prompts below to use the energy lens.

ADDITIONAL GUIDANCE	Students may benefit from having the M-E-F poster visible to support their thinking. If you find that students were struggling with the questions about forces, be sure to display the poster going forward.

Suggested prompt	Sample student response
Why is energy in the field lower in this middle region between the humps?	We have to add energy to pull apart the particles in the nucleus.
Where is the energy going as the particles shoot off to the sides?	It is transferring to the particles as they repel. (If students do not suggest this, point out to them that kinetic energy is not listed and ask them to suggest what its graph would look like if overlaid on the total energy and energy in the field graphs.)

Complete the discussion by focusing on what forces can help us explain. Keep projecting https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission and use the prompts below to use the force lens.

Suggested prompt	Sample student response

Suggested prompt	Sample student response
How can the forces help explain what we see in terms of energy transfer into and out of fields?	Energy has to be put into the fields with the strong nuclear force to pull and break the nucleus apart (this was the wobble). Where the electric field is stronger, the particles are repelling, and energy is transferring out of the field to the particles. Electrostatic forces would be really strong if the particles are so close initially, so this would cause a lot of energy to transfer from the field to the particles as they repel.
How is this relationship between forces and energy similar to what is happening in chemical reactions?	Forces transfer energy. Fields produced by matter can store energy between the particles of that matter.

ADDITIONAL GUIDANCE

Students may be surprised that energy transfers to the field as the new nuclei get farther apart instead of as they come closer together. This is because the new nuclei, having positive charges, will repel. The simulation from *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* referenced in Lesson 4 can help re-establish this idea if needed.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should evaluate how the data from the reading affects our working explanation of how nuclear fission provides energy. (SEP: 4.5; DCI: PS3.C.1)
- Students identify that nuclear fission must include a different force relationship between components than chemical processes do. (CCC: 6.1)
- Students track energy transfers in and out of nuclear and electric fields, which results in massive energy transfer out of the system from electric fields. (DCI: PS3.C.1)

What to do: Students are leveraging their understanding from Lesson Set 1, summarized in Lesson 8, to apply their data to their working explanation about where the energy comes from in nuclear processes. It may be beneficial to bring out the consensus model from that lesson and ask students to compare where "bonds" are breaking and forming and what that would mean for energy transfer into and out of fields. Do not expect students to explain why certain isotopes do or do not exist.

Building toward 11.B.1 Evaluate the impact of new data related to nucleus structures on the model of energy transfer in and out of fields during nuclear fission. (SEP: 4.5; DCI: PS3.C.1, PS1.C.1; CCC: 6.1)

End of day 2

11 · NAVIGATE

4 min

MATERIALS: science notebook

Recall our working explanation. Display **slide S**. Give students 2 minutes to stop and jot in their science notebooks about the prompt. Then use the prompts below to lead a discussion.

Suggested prompt	Sample student response
Where is the energy coming from when we use uranium as a fuel?	It is coming from the electric fields. It is released not when the strong nuclear force "bonds" break apart, but when the new nuclei repel.
How much energy can uranium provide?	A lot. We think a lot, but we do not remember exactly how much more.

Say, *It might be helpful to re-attach numbers to how much more energy uranium can provide than other fuels.*

12 · COMPARE ENERGY RELEASED VALUES

5 min

MATERIALS: Fuel Data Cards from Lesson 1

Introduce the task. Organize students into groups of 5. Display **slide T** and distribute Fuel Data Cards from Lesson 1. Instruct students to discuss the prompt on **slide T** with their group. They will not share their discussions at this point. Rather, they will share them during the whole-class discussion on the next slide.

Discuss energy released values. Display **slide U**. Lead students in reflecting on the differences between fuels.

Suggested prompt	Sample student response
What differences did you see between fuels?	Uranium provides way more energy than other fuels.
What do you think of the differences you saw?	Uranium sounds really promising as a use instead of fossil fuels. Maybe uranium would be a good fuel, but it is dangerous. There must be some good reason why we do not use nuclear fission in everything.

Ask students to brainstorm why we do not use nuclear reactors for all transportation, just ships or submarines. Listen for these ideas:

- Nuclear fission might be expensive.
- It might be scary or dangerous.
- Nuclear reactors might not fit on cars or might be difficult to care for.

Say, *We have ideas about some of these engineering implications, but we need more information. I have some readings that might help us out.*

13 · READ ABOUT DIFFERENT ASPECTS OF NUCLEAR FISSION USE FOR TRANSPORTATION AND ELECTRICITY

20 min

MATERIALS: *Safety: Control Rods*, *Environment: Nuclear Waste*, *Safety: Supply Chain*, *Infrastructure: Nuclear Plants*

Set up the jigsaw task. Place students in groups of four and assign each student a different reading - *Safety: Control Rods*, *Environment: Nuclear Waste*, *Safety: Supply Chain*, or *Infrastructure: Nuclear Plants*.✱ Display **slide V**. Explain to students that they will work with their groups to answer the questions on their reading. Give students 6 minutes to individually read and process the material.

ADDITIONAL GUIDANCE

Encourage students to listen to each other carefully throughout the debrief portions of the activity. The goal is for students to get a complete picture of nuclear fission's advantages as a fuel source as well as the barriers that stand between its use to fuel everyday vehicles. Although students will not discuss the effects of radiation on the human body until *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*, emphasize to students that millions of people have lived safe, healthy lives within a few miles of nuclear reactors and uranium deposits --but that does not mean the technology is without risk.

Debrief in like-reading groups. Display **slide W**. Divide the class so that each student is in a group with no more than five people total who read the same reading. Give them 4 minutes to discuss the reading and complete questions 1 and 2.

Share in jigsaw groups. Display **slide X**. Have students return to their original jigsaw groups. Each member of the group should have two minutes to highlight the main idea from their reading and 2-3 supporting details.

ADDITIONAL GUIDANCE

As they think about nuclear fission, students may bring up nuclear weapons, which may rely on nuclear fission. Proceed carefully with any whole-class research into this space, and consult with counselors to support students in discussing nuclear ethics and the possibility of nuclear war. For more information on the types of support students might need, see https://www.pbs.org/newshour/education/talking-to-kids-about-nuclear-tensions-experts-advise-telling-the-truth.

✱ ATTENDING TO EQUITY

Universal Design for Learning: You may wish to promote student *engagement* by allowing students to choose their reading. This can be an effective strategy as long as students are able to debrief their reading with others who read something similar, then hear about all the readings from classmates.

14 · ADD TO PROGRESS TRACKERS

8 min

MATERIALS: *Progress Tracker* from Lesson 2

Add an engineering lens to the readings. Display **slide Y** and have students discuss the unanticipated or unintended effects of uranium fuel and possible implications for criteria and constraints. Listen for these ideas:

- Nuclear fission emits no carbon dioxide and has a high energy released.
- Nuclear reactors can be dangerous if control rods are not operated properly.
- Uranium brings concerns about transportation and waste storage.
- Nuclear reactors are expensive to build and currently too large to fit on a vehicle.
- Mining uranium can harm the environment.
- We need to have new criteria and constraints around safety.
- We need to consider the size of something like an engine.

Say, *I hear some important concerns here - cost, safety, storage, environmental concerns, and others. Given all that we have figured out, let's capture those in our Progress Trackers.*

ADDITIONAL GUIDANCE

It is important to emphasize to students that scientists, engineers and policymakers likely anticipated many of these effects or learned about them early in development of nuclear technology, and bear responsibility for harm that resulted from nuclear projects. However, these effects are not necessarily obvious to citizens learning about nuclear technologies.

Update Progress Trackers. Present **slide Z**. Give students a few minutes to update *Progress Tracker* from Lesson 2, then share if there is time. A sample entry is shown below.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	Engineering implications Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
We saw from models and data that uranium releases energy through fission. The nucleus is hit with neutrons and breaks up. Energy is released from the electric field between positively charged nuclei as they repel apart. We also read about how nuclear waste is hazardous to living things for thousands of years. It must be stored and transported very carefully to prevent unwanted contamination of the environment.	*The cost of building safe nuclear reactors is very high. It doesn't make sense to use uranium as fuel in the more common forms of transportation.*	Avoid: *Unsafe storage of nuclear materials.* Shift: *To safer handling practices and plans for waste.* Improve: *Safety technology for nuclear technology, although nuclear engineers nowadays are doing the most to keep it safe. Control rods are critical to safe fission and have killed people when not used properly. Also improving waste storage technology so we don't have to blow up sacred lands and mountains just to bury our waste.*

Thank students for their attentiveness to different concerns in engineering and say that we are probably ready to spend more time in that space. But first, this might be a good opportunity for us to check what we have figured out about nuclear fission.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students articulate unanticipated effects in the use of nuclear fission for transportation, including costs and risks like environmental damage, negative health effects, high initial investments, and the need for miniaturization. (SEP: 6.3; DCI: ESS3.A.2)
- Students identify the problems with system design that could result if uranium was used as a fuel without addressing unanticipated effects. (DCI: ESS3.A.2; CCC: 2.3)

What to do: Students will have an opportunity in Lesson Set 3 to compare different potential fuels. However, at this point, students should have articulated a wide variety of costs and risks that could result from haphazard use of nuclear fission. Encourage students to return to the readings to identify additional costs and risks and use this opportunity to also highlight to students that fossil fuels have many of the same problems. Consider collecting students' *Progress Tracker* and giving feedback around how students incorporated thinking about unanticipated effects with the associated costs as we seek to design improved systems.

Building toward 11.C.1 Apply scientific ideas, principles, and evidence to identify unanticipated effects of a transportation design solution that may result in problems in the system due to associated costs and risks. (SEP: 6.3; DCI: ESS3.A.2; CCC: 2.3)

15 · COMPLETE AN ELECTRONIC EXIT TICKET

8 min

MATERIALS: Electronic Exit Ticket, internet-connected device, *Electronic Exit Tickets* from Lesson 5

ADDITIONAL GUIDANCE

See *Electronic Exit Tickets* from Lesson 5 to create the Electronic Exit Ticket for your classes using https://docs.google.com/forms/d/1Hquul2ebA8b9ROGHxNwPiok5ZRZCh1lhQSlbEx9LIn8/copy.

Complete an Electronic Exit Ticket. Display **slide AA**. Give students the remainder of class to complete the Electronic Exit Ticket.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *L11 Electronic Exit Ticket* for guidance.

What to do: See *L11 Electronic Exit Ticket* for guidance.

Building toward 11.A.4 Construct an explanation based on a variety of sources using structure-function relationships to show how protons and neutrons are conserved during nuclear fission while energy is released. (SEP: 6.2; DCI: PS1.C.1; CCC: 6.1, 5.5)

ADDITIONAL GUIDANCE

The next lesson, Lesson 12, can be deployed in multiple ways depending on need and time constraints. Students will compare chemical and nuclear rockets. Consider deploying the lesson at this time if any of the following apply:

- Students are particularly interested in nuclear reactors or need more time to wrestle with how they work.
- Students were particularly interested in *Space Survival Unit*, given the phenomenon embedded in the Lesson 12 task.
- You wish to give students an additional opportunity for practicing engineering thinking before the major engineering task in Lesson Set 3.
- You wish to assess students' engineering thinking (previously developed in *Oysters Unit*) before Lesson Set 3.

If none of these apply, you may choose to omit Lesson 12 or use it as a post-assessment of engineering thinking after the Driving Question Board clear-out in Lesson 15.

Additional Lesson 11 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-LITERACY.RST.9-10.10: By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently

Students interpret the meaning of a system diagram of a nuclear reactor, map what they read about forces to an energy graph, and independently read texts about different factors surrounding nuclear energy, summarizing these texts to their peers.

LESSON 12: How can our knowledge of fuel trade-offs support our evaluation of future rocket fuels?

PREVIOUS LESSON

Having not explained uranium fuel yet, we analyzed the structure of a nuclear reactor. We applied M-E-F lenses to nuclear fission. We analyzed data on protons and neutrons and read about the strong nuclear force. We jigsawed articles that described concerns with uranium as a fuel, updated our Progress Trackers, and completed an Electronic Exit Ticket.

THIS LESSON

PUTTING PIECES TOGETHER

1 day



NASA

We examine the environmental impact from the increase in space flights leaving Earth's atmosphere. We observe a video showing the process of how astronauts will reach Mars. We develop a list of criteria and constraints that engineers and scientists need to explore when choosing a rocket fuel. We read an article comparing the differences between chemical and nuclear rockets. We then work in groups to rank our criteria and constraints and compare each type of rocket against them. Finally, we individually argue for which, or neither, fuel should be used in future space missions.

NEXT LESSON

We will create a draft decision matrix and use it to evaluate transportation system solutions. We will work in small groups to develop subcategories for the criteria and constraints in our consensus decision matrix.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

12.A Compare and evaluate competing rocket fuel options for future space missions specifying qualitative and quantitative criteria and constraints that account for societal want of space exploration and environmental impact. (SEP: 7.1; DCI: ETS1.A.1, ETS1.A.2; CCC: 2.3)

WHAT STUDENTS WILL FIGURE OUT

- More space flights using carbon-based fuels is harming the atmosphere.
- Uranium has a much higher energy released than hydrogen fuels.
- Hydrogen-fueled rockets release no harmful products, while nuclear rockets' exhaust is radioactive.
- Nuclear-powered rockets will lead to less travel time, which means astronauts will be exposed to less cosmic radiation than if traveling in chemical-fueled rockets.

Lesson 12 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		**NAVIGATE** Re-center students to the major takeaways from the previous lesson.	A	
2	9 min		**ORIENT TO SPACE TRAVEL PHENOMENON** Help students clarify an engineering challenge for future space missions by investigating the negative impacts of space travel.	B-D	*Space Launch Impact*, https://youtu.be/_-9Ee-ooPYI
3	10 min		**BUILD A CLASS CRITERIA AND CONSTRAINTS CHART** Lead a Scientists Circle for students to develop a list of criteria and constraints for future space missions.	E	chart paper, chart paper markers
4	12 min		**EVALUATE ROCKET FUEL CRITERIA AND CONSTRAINTS** Support students as they use an article to evaluate the class criteria and constraints and how each type of rocket supports or ignores them.	F-G	*Rocket Comparisons*
5	10 min		**DEVELOP AN ARGUMENT FOR FUEL CHOICE** Give students time to compare nuclear and hydrogen rocket fuels in a written argument.	H	*Rocket Fuel Argument*

End of day 1

Lesson 12 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Space Launch Impact* • *Rocket Comparisons* • *Rocket Fuel Argument*		• https://youtu.be/_-9Ee-ooPYI • chart paper • chart paper markers

Materials preparation (30 minutes)

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

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

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

Have a piece of chart paper ready for building the consensus criteria and constraint list.

Print out individual copies of *Space Launch Impact* and *Rocket Comparisons* for each student. These may be reused across classes.

Lesson 12 • Where We Are Going and NOT Going

Where We Are Going

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

- **ETS1.A.1 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.
- **ETS1.A.2 Defining and Delimiting Engineering Problems:** Humanity faces major global challenges today, ~~such as the need for supplies of clean water and food or~~ for energy sources that minimize pollution, which can be addressed through engineering. ~~These global challenges also may have manifestations in local communities~~.

Crossout explanations: Risk mitigation will be more completely explored in Lesson 14 as students evaluate the safety of different transportation options. Students considered clean water and food, and manifestations in local communities, in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. They will return to manifestations of global challenges' impacts in local communities in Lesson 15.

Students are introduced to an ongoing design challenge that involves the design question of using different fuel sources to power society's increased space missions (CCC: 2.3). Students use a modified abstract from a published journal article and a video about completing a future space mission to unpack the criteria and constraints of this design solution, which include minimizing pollution (DCI: ETS1.A1, ETS1.A2). From here, students come together to create a consensus Criteria and Constraints chart that they use to argue for the optimal fuel choice (SEP: 7.1). Before making this argument, students use an article to further refine their class list of criteria and constraints. Students' thinking in this lesson will continue the work done in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, where students began to consider the idea of trade-offs and engineering design. Students will make a similar argument, in a more complex system, in Lesson 13.

This lesson is intended to meet students' ongoing curiosities about the use of uranium in transportation, particularly if students were interested in the anchoring phenomenon of *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. It also provides students a miniature opportunity to use engineering thinking from *Oysters Unit* before taking on the transportation system-level project in Lesson Set 3. If you do not feel any of those conditions are student needs at this time, you may navigate directly into Lesson 13 and use this lesson as an end-of-unit assessment, or omit it entirely.

Where We Are NOT Going

As students evaluate the different types of rocket fuels, they will not take risk mitigation into account. The engineering problem of future space fuels also does not address other global challenges like supplying food or clean water. The resource management needed for successful space missions will not be broached. Students' evaluations should be focused on the energy demands and environmental impacts of future space missions, through a global rather than local community lens.

LEARNING PLAN for LESSON 12

1 · NAVIGATE

4 min

MATERIALS: None

Ask students to consider the benefits and drawbacks of using nuclear fission to power transportation. Display **slide A**. Have students call back to their learning from Lesson 11 by discussing the prompts on the slide with a partner.

Suggested prompt	Sample student response
What were the benefits and risks of using uranium as a fuel source?	Uranium has a really high energy released. Uranium doesn't produce carbon dioxide. It releases harmful radiation. It's hard to dispose of the used-up radioactive fuel.
Are there any possible transportation applications where uranium could be a useful alternative?	We could use it to power transport ships since they require so much fuel. Space travel!

If students do not suggest space travel as an option, draw on the benefits and risks they suggest to elicit ideas about applications that are not near people and that require a lot of energy. Students may or may not draw on knowledge from *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

2 · ORIENT TO SPACE TRAVEL PHENOMENON

9 min

MATERIALS: science notebook, *Space Launch Impact*, https://youtu.be/_-9Ee-ooPYI

Introduce the environmental dilemma. Say, *We have generated some great understandings of uranium and its potential as a fuel source. I think there is an engineering dilemma that we could use this knowledge to analyze. In the last few years, there has been a growing concern around the impacts that more space missions have on our environment. Let's take a closer look at this concern.* Display **slide B** and have a student, or the teacher, read aloud the headline to the class, then distribute *Space Launch Impact* to each student. Give students a few minutes to read and possibly annotate the journal abstract using a pre-established routine. When students finish, lead a short discussion to make sense of the headline on the slide and *Space Launch Impact*.

Suggested prompt	Sample student response
What goals are we trying to achieve with our space travel? ✱	Get to the moon or Mars. Scientific missions to other planets. Have people travel to space.

✱ ATTENDING TO EQUITY

This lesson's connection to space travel may recapture the interest of students who need a break from the problem of carbon dioxide emissions in our terrestrial transportation system.

Suggested prompt	Sample student response
What do we notice about the trade-offs of space travel?	More flights are harming our environment. It takes a lot of resources to travel to and survive in space. There are scientific reasons to explore space.
What have we figured out in this unit that might help us address the growing environmental concern?	Accept all responses.

Watch a NASA Mars travel video. Say, *We know that there are many types of space missions, but what exactly does this have to do with fuels? Let's take a moment to learn about one of these missions to see if we can uncover some criteria and constraints that center our fuel knowledge.* Display **slide C** and instruct students to draw a Notice and Wonder chart in their science notebooks. Let students know that they are about to watch a video that shows the process of sending humans to Mars.

As they watch the video, students should record noticings and wonderings about the criteria and constraints that must be met to achieve a successful space mission. It may be useful for students to refer to their Progress Trackers to compare with other fuel criteria and constraints. Students should pay special attention to the energy constraints of space travel. Give students a minute or two after the completion of the video to finish their thinking.

Discuss noticings and wonderings. Display **slide D** and ask students to discuss the question prompts on the slide with their partner. If their partner has any additional noticings or wonderings, remind students to add them to their science notebook. Possible responses to listen for:

Suggested prompt	Sample student response
What did you notice about the process of getting to Mars?	You can't travel in straight lines. You have to time it just right. Energy seems to be the most important thing to consider.
What sorts of energy constraints must we account for when planning missions to Mars or to other places?	We have to travel with many of the resources we need. Weight means we need more fuel. Since we have to travel so far and launch off of two planets, we will need a lot of energy.
What are some other criteria that need to be considered when planning for non-Mars space missions?	Allowing for longer mission time. Making it easier to time the launch. Bringing more stuff.

ADDITIONAL GUIDANCE

Normally after students have shared with their partner, teachers would have students share ideas as a class. Here, we would recommend skipping the whole group share-out and instead save these ideas for the Scientists Circle discussion.

3 · BUILD A CLASS CRITERIA AND CONSTRAINTS CHART

10 min

MATERIALS: science notebook, chart paper, chart paper markers

Build a class criteria and constraints chart. Display **slide E** and say, *We have figured out a lot about different fuels and their applications. Using those different applications and what the many space missions will entail, let's build a chart that will help us compare two possible rocket fuels.* Lead a discussion using the prompts on the slide. As students share criteria and constraints, group into categories. Some suggestions are below.

Suggested prompt	Sample student response
What energy constraints must we account for when planning space missions?	We will need to move a lot of stuff, which will require a lot of fuel. Since the destinations are so far away, we will need a lot of energy to make the trip.
What are some other criteria that need to be considered when choosing the optimal rocket fuel?	The fuels need to be safe for the environment. It shouldn't cost too much. The fuels should also be safe for the astronauts--going to space is dangerous already! Can nuclear rockets actually be built?

Take a few minutes to organize the student-generated categories into a format nominated by the students (table, Venn diagram, etc.). This is an opportunity to have students work as a community to construct an analytical tool that they will use individually later. Make sure you leave room for a way to rank the categories by importance. Your Criteria and Constraints chart could look something like the following:

Categories	Hydrogen-based rocket	Nuclear-based rocket
Weight		
Energy released		
Timing		
Safety		
Environmental impact		

ADDITIONAL GUIDANCE

Your Criteria and Constraints chart may look different from the example shown. This chart is modeled after a similar one that students will create in Lesson 13.

Say, *I heard ideas about different criteria and constraints that we will have to define for the fuel that powers our next-generation rockets. As we look at these different criteria and constraints, should we look at each of them equally or are some of greater importance than others?*

Suggested prompt	Sample student response
Which of these criteria and constraints are most important?	Well, going to space is expensive, so I think cost is an important one. But a successful mission is one where the astronauts are safe. So their safety has to be one of the more important ones.
Which of them are least important?	Timing because we orbit the sun, so there's likely another time where we could launch the rocket.
Is this ranking shared for all interest holders?	Well I guess some other countries don't care about going to space so they just don't want the Earth harmed. Astronauts don't care about cost, they just want to be safe and be able to get back.

Say, *Now that we have a way of comparing the different fuel choices for future space missions, lets apply this tool in an individual evaluation of nuclear- and hydrogen-based rockets.* Once the class has built consensus around the ranking of the criteria and constraints, have students go to their table groups.

4 · EVALUATE ROCKET FUEL CRITERIA AND CONSTRAINTS

12 min

MATERIALS: science notebook, *Rocket Comparisons*

Evaluate and use class criteria and constraints for rocket fuels. Display **slide F** and distribute *Rocket Comparisons*. Have students read the reference in groups, annotating as needed. The goal of the reading is to help students add to the class Criteria and Constraints chart and to use this revised chart to do an initial evaluation of how chemically-fueled and nuclear-fueled rockets meet the criteria and constraints.

ALTERNATE ACTIVITY

Literacy and Comprehension Support. For students who benefit from additional reading comprehension support, the Coherent Reading Protocol is well-suited for this text. This protocol guides students to monitor their understanding after each chunk of text, identify the main idea, and connect the information in the reading to the lesson question. The Coherent Reading Protocol can be found in the Teacher Handbook.

After groups have discussed revisions to the criteria and constraints and made initial comparisons of the fuels, display **slide G**. To debrief students' comparisons, have them share their answers to the prompts on the slide.

Suggested prompt	Sample student response
Is there anything we need to add to our list of criteria and constraints?	Travel time seems to be important because longer flights are more dangerous to the astronauts. Energy released, because nuclear fuels have a lot more energy than either of the chemical fuel options.
How does the reading support or contradict your current ranking of criteria?	Environmental impact needs to be higher up. Travel time and energy released seem really important for the astronauts.

Suggest that students take their classmates' ideas about revised criteria and rankings into account as they think more about the fuel choices at hand.

5 · DEVELOP AN ARGUMENT FOR FUEL CHOICE

10 min

MATERIALS: *Rocket Fuel Argument*

Students argue their fuel choice using evidence. Display **slide H**, distribute *Rocket Fuel Argument*, and tell students that they will now be arguing which fuel choice, if any, meets the criteria and constraints for an optimal rocket fuel for our future space missions. Students' arguments should begin by defining the problem that we are looking to overcome. Students should include the rationale for their choice.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students compare arguments for possible rocket fuels in light of new environmental impacts to generate the criteria and constraints of future space missions. (SEP: 7.1; DCI: ETS1.A.1)
- Students propose a rocket fuel source or other possibilities to help minimize negative impacts (e.g., environmental) and maximize positive results. (DCI: ETS1.A.2; CCC: 2.3)

What to do: Have students use the class-generated Criteria and Constraints chart. Refer to *Rocket Fuel Argument Key* for additional guidance and ideas. Feedback provided here will be particularly useful in Lesson 13, when students make similar comparisons in a more complex system.

Building toward 12.A Compare and evaluate competing rocket fuel options for future space missions specifying qualitative and quantitative criteria and constraints that account for societal want of space exploration and environmental impact. (SEP: 7.1; DCI: ETS1.A.1, ETS1.A.2; CCC: 2.3)

Additional Lesson 12 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources ~~(including their own experiments)~~, noting when the findings support or contradict previous explanations or accounts.

CCSS.ELA-LITERACY.WHST.9-10.9: Draw evidence from informational texts to support analysis, ~~reflection, and research.~~

CCSS.ELA-LITERACY.WHST.9-10.1: Write arguments focused on discipline-specific content.

In writing, students compare arguments for different rocket fuels, drawing on evidence from texts.

LESSON 13: Why do we use some fuels rather than others?

PREVIOUS LESSON

We examined the environmental impact from the increase in space flights leaving Earth's atmosphere. We developed criteria and constraints for choosing a rocket fuel and used an article comparing chemical and nuclear rockets to refine our class list. We argued individually for which, or neither, fuel should be used in future space missions.

THIS LESSON

PROBLEMATIZING, INVESTIGATION

2 days



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We create a draft decision matrix and use it to evaluate transportation solutions and their various impacts based on different criteria and constraints. In doing so, we realize that our initial groupings are too complex and should be broken into subcategories so that we can evaluate solutions systematically. We work in small groups to develop subcategories for the other criteria and constraints in our consensus decision matrix.

NEXT LESSON

We will consider our personal values to prioritize five categories of criteria/constraints. We will evaluate transportation options using radar charts to visualize how they meet the criteria/constraints. We will complete cost-benefit calculations and generate arguments for our top three transportation options. We will share these arguments with classmates.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

13.A Compare and evaluate the potential impacts of two transportation options (current state vs. possible future state) caused by the engineering approach (shift, avoid, improve) as well as the availability and accessibility of the needed resources. (SEP: 7.1; DCI: ETS1.B.1, ESS3.A.1; CCC: 2.4)

13.B Present an oral and written argument for the need for specific subcategories of criteria that can be approached systematically, based on data and evidence, that shows differential effects such as benefits and costs resulting from changes in the transportation system. (SEP: 7.4; DCI: ETS1.C.1, ESS3.A.2; CCC: 2.4)

WHAT STUDENTS WILL FIGURE OUT

- Evaluating the benefits of different transportation solutions requires comparison against clear criteria and constraints. Each transportation solution has trade-offs that must be considered before implementation.
- It is helpful to break large, broad criteria into smaller, more specific parts to better evaluate possible solutions.

Lesson 13 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Have students turn and talk with a partner to discuss where they left off last class and think about what else we need to consider with regard to fuels.	A	3x3 sticky notes, Driving Question Board
2	12 min		**IDENTIFY TRANSPORTATION TRADE-OFFS AND GOALS** Lead a whole-class discussion to motivate the different transportation goals for which we need to identify criteria and constraints.	B-C	
3	16 min		**ANALYZE POTENTIAL TRANSPORTATION SOLUTIONS FOR CRITERIA AND CONSTRAINTS** Organize students into groups of 4-5 to analyze transportation solutions addressing one of the transportation goals.	D-F	*Potential Transportation Analysis*, *Transportation System Solutions*
4	12 min		**DEVELOP A CONSENSUS DECISION MATRIX** Facilitate the class in developing a transportation decision matrix.	G-H	*Potential Transportation Analysis*, chart paper, chart paper markers
					End of day 1
5	2 min		**NAVIGATE** Have students turn and talk with a partner to reflect on the class's decision matrix.	I	
6	13 min	☑	**EVALUATE A TRANSPORTATION SOLUTION USING THE DECISION MATRIX** Have students individually evaluate their assigned transportation solution using the consensus decision matrix.	J	*Utilizing Decision Matrix*, *Transportation System Solutions*, Consensus Decision Matrix poster
7	3 min		**REFLECT ON OUR DECISION MATRIX** Give students an opportunity to discuss their experiences with the class decision matrix, to motivate subcategories.	K	
8	14 min	☑	**DEVELOP SUBCATEGORIES** Organize students into pairs to identify 3-4 subcategories for the criteria and constraints groupings. Update the consensus decision matrix to include agreed-upon subcategories.	L-N	*Transportation Solution Drawbacks*, *Transportation System Solutions*, Fuel Data Cards, Consensus Decision Matrix poster, chart paper markers
9	12 min	☑	**ARGUE FOR SUBCATEGORIES** Have groups argue for their subcategories to be added to the criteria and constraints on the consensus decision matrix.	O	Consensus Decision Matrix poster, chart paper markers
10	1 min		**NAVIGATE** Lead a class discussion to motivate students to think about how we could implement our consensus decision matrix.	P	
					End of day 2

Lesson 13 • Materials List

	per student	per group	per class
Lesson materials	• 3x3 sticky notes • science notebook • *Potential Transportation Analysis* • *Utilizing Decision Matrix* • *Transportation System Solutions* • *Transportation Solution Drawbacks*	• *Transportation System Solutions* • Fuel Data Cards	• Driving Question Board • chart paper • chart paper markers • Consensus Decision Matrix poster

Materials preparation (30 minutes)

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

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

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

Lesson Set 3 utilizes portfolio-style grading to generate meaningful feedback for students throughout Lessons 13-15, called the Standards Aligned Matrix of Progress (STAMP) protocol. Read through *STAMP Assessment Guidance* to orient yourself on how to use the STAMP protocol.

Print one copy of *STAMP Protocol Matrix* for each section of OpenSciEd Chemistry you teach and write or type in students' names in the first column. You will be responsible for keeping track of students' total stamp counts on *STAMP Protocol Matrix*. If you have a different system for your class, use it. Alternatively, students may monitor their own stamps by adding them to their science notebooks to reflect on their learning. The most important part of this process is integrating performance expectation-aligned teacher feedback into the moment-to-moment activities of the class.

Have a piece of chart paper ready to record the draft decision matrix on day 1 and update it on day 2.

Groups will be assigned one of the vignettes found in *Transportation System Solutions* and *Transportation Solution Drawbacks*. Make copies and separate each of the vignettes for each group.

Have the Fuel Data Cards from Lesson 1 available to use on day 2.

Lesson 13 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS3.A.1 Natural Resources:** Resource availability has guided ~~the development of~~ human society.
- **ESS3.A.2 Natural Resources:** All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.
- **ETS1.B.1 Developing Possible Solutions:** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
- **ETS1.C.1 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.

Crossout explanation: How resource availability guided the development of human society was previously explored in Lesson 5. This element was also developed in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. The other engineering ideas were previously built in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

Students take stock of the criteria and constraints they have added to their Progress Trackers throughout the unit. They work in small groups to analyze a transportation solution to identify various criteria and constraints. These criteria and constraints are used to develop a draft decision matrix (DCI: ETS1.B.1). Students use the decision matrix to *compare two transportation solutions* (SEP: 7.1), using a similar practice to that in Lesson 12. The decision matrix should motivate students to analyze each transportation solution along the basis of *cost, safety, reliability, and aesthetics, as well as social, cultural, and other environmental impacts* such as *resource availability*, water quality, monetary needs, and land use (DCI: ESS3.A.1, ETS1.B.1). Students identify which transportation system is better in terms of its impacts and *share their reasoning* (SEP: 7.1). Students then look at a drawback for their assigned transportation solution, which prompts them to consider the difficulty in using a *broad consideration* and the *need for subcategories* (DCI: ETS1.C.1). Students work in groups to *develop subcategories for criteria and constraints* based on the *different effects* the solution may have (DCI: ESS3.A.2, ETS1.C.1; CCC: 2.4). As in Lesson 6, they present *oral arguments supported with evidence* to the class for why the *subcategories* should be included in the consensus decision matrix (SEP: 7.4; DCI: ETS1.C.1).

Where We Are NOT Going

The purpose of evaluating the two transportation solutions in this lesson is not to make a decision about one option over another. The goal is to illustrate how the evaluative process is complex and to motivate the need to expand it. Students will evaluate transportation options for the sake of selection in Lesson 14.

LEARNING PLAN for LESSON 13

1 · NAVIGATE

5 min

MATERIALS: 3x3 sticky notes, Driving Question Board

Navigate. Have students take two minutes to discuss the prompts on **slide A**. Display the Driving Question Board. After two minutes, ask for volunteers to share what their partner said.

Suggested prompt	Sample student response
What are some key takeaways that you have after looking at so many possible fuels?	Reducing the amount of carbon dioxide is hard. Each fuel has good things we want, but bad things that are dangerous. Even "green" fuels cause carbon to be released or harm the environment.
What other wonderings or concerns have come up for you?	Accept all responses.

Leverage student questions to suggest that we think about the transportation system as a whole, which will allow us to both follow up with questions about specific fuels and reflect on how we could improve our transportation system. Have students record new questions and post them on the Driving Question Board. As students work through Lesson Set 3, assist them in finding answers to these questions if they will help students develop design solutions.

2 · IDENTIFY TRANSPORTATION TRADE-OFFS AND GOALS

12 min

MATERIALS: science notebook

Think back to our needs for transportation. Display **slide B**. Ask students to consider the transportation of goods across large distances. Tie these criteria and constraints to the trade-offs being made to accomplish those goals.

Suggested prompt	Sample student response
What have we been using carbon-based fuels to transport?	We drive ourselves. We ship things across the world. Things we need are moved.
Where do we move things using carbon-based fuels?	Across town. To school. From city to city. Internationally, by ships and trains and airplanes.

Suggested prompt	Sample student response
What trade-offs have we been making through our use of carbon-based fuels?	When we move these things or people we add CO_2 to the atmosphere. We pollute the world as this happens. Communities can be harmed when fuels are obtained and processed.

Identify criteria and constraints for various transportation goals. Display **slide C.** Say, *So we have different types of transportation goals that we need to plan for. Let's try organizing these goals in a matrix. A* matrix *is a word engineers and scientists use to describe a tool that lets us compare components across multiple variables.* Share with students that you hear them say that we are moving both things (cargo) and people. These things are then being moved both short and long distances. Point out that we identified criteria and constraints throughout the unit, but students did not always attach them to particular goals like these.

Ask students to take out *Progress Tracker* and reflect on how criteria and constraints we already identified might correspond to these different goals.

Ask students to share some criteria and constraints for different transportation goals. Type these contributions into the matrix on **slide C**. Be sure to direct students to record this matrix into their science notebooks.

Suggested prompt	Sample student response
What are some criteria and constraints for moving people short distances?	Should be easy and quick. Don't need as much fuel. Get people where they need to go without causing other people to be late. Needs to reach a lot of different places.
What are some criteria and constraints for moving people long distances?	Need to use efficient fuels. Need to go to a lot of cities, but not as many places as shorter distances. Need more fuel to power the vehicle farther distances. Can go over or around barriers like mountains.
What are some criteria and constraints for moving things short distances?	Need to arrive on time. Has to reach lots of different places so people can get their stuff. Need more fuel to carry heavy things.

Suggested prompt	Sample student response
What are some criteria and constraints for moving things long distances?	Carry heavy, or lots of, things over oceans or large land areas. It requires a lot of fuel. Every place needs different things.

An example Transportation Goal Matrix is shown:

	People	Things
Short Distances	• *Should be easy and quick.* • *Don't need as much fuel.* • *Get people where they need to go without causing other people to be late.* • *Needs to reach a lot of different places.*	• *Need to arrive on time.* • *Has to reach lots of different places so people can get their stuff.* • *Need more fuel to carry heavy things.* •
Long Distances	• *Need to use efficient fuels.* • *Need to go to a lot of cities, but not as many places as shorter distances.* • *Need more fuel to power the vehicle farther distances.* • *Can go over or around barriers like mountains.*	• *Carry heavy, or lots of, things over oceans or large land areas.* • *It requires a lot of fuel.* • *Every place needs different things.*

3 · ANALYZE POTENTIAL TRANSPORTATION SOLUTIONS FOR CRITERIA AND CONSTRAINTS

16 min

MATERIALS: *Potential Transportation Analysis*, science notebook, *Transportation System Solutions*

Unpack recent transportation solutions. Display **slide D**. Remind students about the noticings we made at the outset of the unit where we observed CO_2 emissions from transportation systems remaining unchanged. Inform students that they will be working in groups to analyze one of the transportation solutions. Organize students into groups of 4-5 and then distribute *Potential Transportation Analysis* to each student and multiple copies of a single solution vignette from *Transportation System Solutions* to each group. Before groups start, remind them to consider the four criteria and constraints on the slide.

After students have had a chance to analyze their assigned solution using *Potential Transportation Analysis*, display **slide E** and debrief as a class using the prompts on the slide.

Suggested prompt	Sample student response
What engineering goal was addressed by your potential transportation solution?	Avoid. Shift. Improve.

Suggested prompt	Sample student response
What evidence was used to support the proposed solution?	The retail delivery fee could reduce CO_2 emissions. The CarGo Tram could reduce emissions by 16%. Microtransit in major cities reduced carbon dioxide by 4,853 tons.
What are some trade-offs that might come into play if this solution is used in other locations?	Ammonia used in the tankers is harmful if spilled. Retail delivery fee costs more money for consumers. The microtransit solution could reduce the number of buses.
What are potential barriers in resource availability that might prevent this solution from being implemented in other locations, or that might negatively affect communities?	The city might not be able to afford all of the new vans. You need water in order for water taxis to matter. Can we make enough biofuels for the planes?

Display **slide F** and ask students to take out their Progress Trackers. Have students discuss with a partner what other criteria and constraints we have seen when investigating different fuels. Suggest that it might be helpful to have a way to organize the criteria and constraints so that we can use them in our evaluations. Point students back to Lesson 12 as an example, if you used that lesson.

4 · DEVELOP A CONSENSUS DECISION MATRIX

12 min

MATERIALS: *Potential Transportation Analysis*, science notebook, chart paper, chart paper markers

Introduce the decision matrix tool. Display **slide G** and describe to students what a decision matrix is and what question we hope to answer by using it. Then invite students to form a Scientists Circle.

Display **slide H**. Ask a previously identified group to share their transportation solution criteria and constraints with the class. As they share, check in with students to show whether they agree that these criteria and constraints apply before adding them to the decision matrix chart paper. Start by building a class list of criteria and constraints. Finally, ask students how we could organize these larger groupings into a matrix format so that we can compare two different transportation solutions later on. Possible formats are shown in *Consensus Decision Matrix*. Leave space under each grouping so that you can add subcategories on day 2.

Continue working as a class to develop a consensus decision matrix. Some prompts that can help facilitate this discussion include:

- What criteria should we make sure to include?
- What constraints should we include?
- Does it seem that different communities have access to the materials needed to implement these practices?
- Do you agree with ___? Why or why not?

When the class has finished their decision matrix, have students copy the finished version into their science notebooks.

ADDITIONAL GUIDANCE

When creating the class consensus decision matrix, avoid adding different fuels or transportation solutions at this point. In Lesson 14 students will narrow down the number of fuels, or transportation system solutions, that they will consider on the decision matrix. The consensus decision matrix should have a row/column where two transportation solutions will go. You might say something like, *We have considered a lot of different possibilities so far. It might be really messy to try to put them all on this matrix right away.*

KEY IDEAS

Purpose of this discussion: Collaboratively develop the list of criteria and constraints for any possible new transportation solution. It is not imperative to categorize the ideas as they are shared; rather, use each category as a way to prompt for different ideas represented in students' transportation solutions.

Listen for these ideas:

- Safety/Health
- Cost
- Environmental Impact
- Energy Released
- Infrastructure/Availability

End of day 1

5 · NAVIGATE

2 min

MATERIALS: science notebook

Reflect on the consensus decision matrix. Display **slide I**. Remind students that last class they developed a consensus decision matrix. Give students two minutes to discuss the prompt on the slide with a partner. Students will not publicly share their discussion at this point.

- What are some challenges we might have when using our decision matrix for decision-making?

Say, *As I walked around the room, I heard people saying that some of our criteria and constraints might be hard to judge, and that it is hard to tell what challenges we might encounter until we try using the decision matrix. Let's try it out and then see if we can expand our tool a bit further.*

6 · EVALUATE A TRANSPORTATION SOLUTION USING THE DECISION MATRIX

13 min

MATERIALS: *Utilizing Decision Matrix*, *Transportation System Solutions*, science notebook, Consensus Decision Matrix poster

Use the consensus decision matrix. Display **slide J** and distribute *Utilizing Decision Matrix*. Talk through the directions on the handout and ask if students have any clarifying questions. Have students copy the consensus decision matrix into *Utilizing Decision Matrix* and then describe how their transportation solution meets or fails to meet each of the criteria and constraints groupings. ✱
As students work to complete their decision matrix analysis, circulate around the room, assist as needed, and conduct the first STAMP protocol check for Lesson 13 using *STAMP Protocol Matrix*. Explain to students that you will come around and conduct a check for understanding by giving students stamps. Encourage students to record the number of stamps they receive as they work.

✱ ATTENDING TO EQUITY

Portfolio-style grading practices such as the one used here have the potential to be more equitable because they emphasize collaborative, low-stakes practice and feedback rather than high-stakes "test" moments. The skills that students demonstrate during these moments also may be more transferable than solo work conducted during an exam. (Bransford et al., 2001)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students consider the effects of implementing new transportation solutions as well as estimate the size of the effects for accessing or implementing those solutions. (DCI: ESS3.A.1; CCC: 2.4)
    - The method is widely available or not available.
    - The solution may have different amounts of positive or negative effects.
- Students identify and compare the benefits and costs (economic, aesthetic, social, cultural, and environmental), safety, and reliability of two transportation system solutions. (SEP: 7.1; DCI: ETS1.B.1)
    - the benefits
    - any financial or other costs
    - any safety concerns
    - Students explain/organize the two solutions (current vs. possible future) in relation to each other.

What to do: Walk around the room and put TWO stamps on *STAMP Protocol Matrix* and students' papers if students have accomplished both of these look-fors. Put ONE stamp on *STAMP Protocol Matrix* if students have accomplished one of the look-fors or part of each look-for. If students do not get two stamps, prompt them to focus on positives and negatives of both transportation solutions as well as causality, and attempt to visit these students again. If you cannot visit all students in the time allotted, you can continue checking in with students at the beginning of the next class. If students have satisfactorily completed this task, encourage them to think through the chemistry of the solution; i.e., What role can a chemical engineer play in this solution? At this early point in the lesson set, students may not think about effect sizes. Provide verbal feedback while stamping students' work.

Building toward 13.A Compare and evaluate the potential impacts of two transportation options (current state vs. possible future state) caused by the engineering approach (shift, avoid, improve) as well as the availability and accessibility of the needed resources. (SEP: 7.1; DCI: ETS1.B.1, ESS3.A.1; CCC: 2.4)

7 · REFLECT ON OUR DECISION MATRIX

3 min

MATERIALS: science notebook

Reflect on our decision matrix. Display **slide K** and discuss students' experiences using the decision matrix.

Suggested prompt	Sample student response
What was difficult about comparing the two transportation methods?	We didn't know how to give it a rating or ranking based on the combination of positive and negative effects. Our groupings seem like they're too broad. It seemed like some of the things that had to do with environmental impact also fell into other categories too, like cost and safety.

Suggested prompt	Sample student response
What might make it easier to compare other transportation solutions or to make a decision for our criteria and constraints?	We need more categories. We should break our groupings down. We need a way to evaluate multiple aspects for each grouping.

8 · DEVELOP SUBCATEGORIES

14 min

MATERIALS: *Transportation Solution Drawbacks*, science notebook, *Transportation System Solutions*, Fuel Data Cards, Consensus Decision Matrix poster, chart paper markers

Break criteria/constraints categories into subcategories. Display **slide L**. Distribute *Transportation Solution Drawbacks* and give students a moment to read their previously assigned section. Have students work with their partner to come up with three to four subcategories for the criteria/constraints grouping that is most relevant to their transportation solution. Have students record these in their science notebook.

ADDITIONAL GUIDANCE

An example of student work is shown below. See the Example Consensus Decision Matrix Draft 2 provided on *Consensus Decision Matrix* for additional ideas of some of the subcategories students may choose to include on the consensus decision matrix and for a layout that will work best.

Drawbacks #1: Hybrid Water Taxis
The addition of the hybrid system to water taxis means it costs more than conventional diesel ferries. Estimates from San Francisco say that crossing the San Francisco Bay on hybrid water taxis could cost about $15,000 per seat if a city chooses to build a 600-passenger ship. Other drawbacks are that the benefit of ***shifting*** to a hybrid system is reduced in cloudy weather, and improper maintenance of the hybrid system reduces its effectiveness.

Criterion/Constraint
- **Cost**

Subcategories:
- **Up-front user cost**
- **Ongoing maintenance**
- **Fuel cost**

Furthering subcategories. Display **slide M**. Have students gather in their small groups, then distribute the Fuel Data Cards to each group and tell students to use these, *Transportation System Solutions*, and *Transportation Solution Drawbacks* to generate any new subcategories that relate to their focal category from the consensus decision matrix. Then, in their notebooks, students can write the subcategories they decide on as well as the reasons they think the subcategories are necessary.

Display **slide N**. After five minutes, pair groups together to form larger groups. Each small group should share their subcategories and reasons for including them. Then as a larger group students will come to consensus on what to include on a list of subcategories that they will present to the class. As groups work, complete the second STAMP protocol check for Lesson 13 using *STAMP Protocol Matrix*. ✱ Again, explain to students that you will be conducting a check for understanding using the STAMP protocol and encourage students to keep track of their stamps in their notebooks.

✱ SUPPORTING STUDENTS IN ENGAGING IN ARGUMENT FROM EVIDENCE

Ensure that students are using *evidence and data from the Fuel Data Cards and transportation solutions and drawbacks readings to develop arguments* for the subcategories they suggest should be included in the consensus decision matrix. Prompt students to clarify what evidence they are using and the source they used. (SEP: 7.4)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use the idea of differential effects (benefits and costs) of transportation solutions to Earth systems. (DCI: ESS3.A.2; CCC: 2.4)
- Students use data and evidence to develop written arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1)

What to do: Walk around the room and put TWO stamps on *STAMP Protocol Matrix* and students' papers if students have multiple subcategories for their criterion AND evidence for the specified subcategories. Put ONE stamp on *STAMP Protocol Matrix* if students have subcategories but lack evidence. If students do not get two stamps, prompt them to go back to the readings and the Fuel Data Cards to connect subcategories to specific evidence.

As students examine a criterion or constraint, ask them to think about how they might define different aspects or subcategories of that criterion or constraint that have opposing effects, based on the information in the readings or the Fuel Data Cards.

Building toward 13.B.1 Present an oral and written argument for the need for specific subcategories of criteria that can be approached systematically, based on data and evidence, that shows differential effects such as benefits and costs resulting from changes in the transportation system. (SEP: 7.4; DCI: ETS1.C.1, ESS3.A.2; CCC: 2.4)

9 · ARGUE FOR SUBCATEGORIES

12 min

MATERIALS: science notebook, Consensus Decision Matrix poster, chart paper markers

Argue for subcategories. Display **slide O**. Give groups time to outline their ideas and add additional evidence from *Transportation Solution Drawbacks*, *Transportation System Solutions*, and the Fuel Data Cards if needed, so that students feel prepared to share their ideas and field follow-up questions from their classmates. If the class agrees, add the subcategories to the related criteria and constraints on the consensus decision matrix. As groups share, complete the third STAMP protocol check for Lesson 13 using *STAMP Protocol Matrix*. Let students know that this will be the final check for understanding for the lesson. If you were not able to reach all students in the prior step, you may prioritize doing so over adding new stamps.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use the idea of differential effects (benefits and costs) of transportation solutions to Earth systems. (DCI: ESS3.A.2; CCC: 2.4)
- Students use data and evidence to develop oral arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1)

What to do: You may listen to groups and provide feedback at a group level, or use student notes to provide individual feedback. As groups share their arguments, put TWO stamps on *STAMP Protocol Matrix* and students' papers if students have multiple subcategories for their criterion AND evidence for the specified subcategories. Put ONE stamp on *STAMP Protocol Matrix* if students have subcategories but lack evidence. If students do not get two stamps, prompt them to go back to the readings and the Fuel Data Cards to connect subcategories to specific evidence.

Building toward 13.B.2 Present an oral and written argument for the need for specific subcategories of criteria that can be approached systematically, based on data and evidence, that shows differential effects such as benefits and costs resulting from changes in the transportation system. (SEP: 7.4; DCI: ETS1.C.1, ESS3.A.2; CCC: 2.4)

10 · NAVIGATE

1 min

MATERIALS: None

Navigate. Display **slide P**. Ask, *What should our next steps be with our consensus decision matrix?* Look for students to suggest:

- We should re-evaluate environmental impacts using the subcategories.
- We can evaluate other potential transportation solutions using the entire decision matrix.
- We can use it to evaluate other transportation choices too.

Additional Lesson 13 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-WRITING.WHST.9-10.9: Draw evidence from informational texts to support analysis~~, reflection, and research~~. Students use evidence from the Fuel Data Cards and two readings to support arguments for adding subcategories for evaluation of criteria and constraints on the consensus decision matrix.

LESSON 14: How do we decide on the best transportation options for our future?

PREVIOUS LESSON

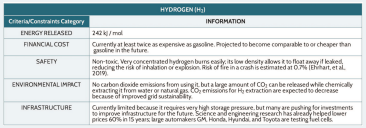
We created a draft decision matrix and used it to evaluate transportation system solutions. We realized that our initial criteria and constraints groupings were too complex and should be broken into subcategories. We worked in small groups to develop subcategories for the other criteria and constraints in our consensus decision matrix.

THIS LESSON

INVESTIGATION

3 days





HYDROGEN (H_2)	
Criteria/Constraint Category	INFORMATION
ENERGY RELEASED	242 kJ / mol
FINANCIAL COST	Currently at least twice as expensive as gasoline. Projected to become comparable to or cheaper than gasoline in the future.
SAFETY	Non-toxic. Very concentrated hydrogen burns easily; its low density allows it to float away if leaked, reducing the risk of inhalation or explosion. Risk of fire in a crash is estimated at 0.7% (Ehrhart, et al., 2019).
ENVIRONMENTAL IMPACT	No carbon dioxide emissions from using it, but a large amount of CO_2 can be released while chemically extracting it from water or natural gas. CO_2 emissions for H_2 extraction are expected to decrease because of improved grid sustainability.
INFRASTRUCTURE	Currently limited because it requires very high storage pressure, but many are pushing for investments to improve infrastructure for the future. Science and engineering research has already helped lower prices 60% in 15 years; large automakers GM, Honda, Hyundai, and Toyota are testing fuel cells.

We consider how our personal values may influence our priorities and decisions. We individually rate which of the criteria or constraints we prioritize most. In small groups, we evaluate our top transportation options by rating them with all five categories of criteria/constraints and input those ratings into radar charts. We individually complete cost-benefit calculations that factor in our personal values and the ratings on our radar charts. We use this analysis to help us generate arguments for our top three transportation options. We share our arguments with other classmates and revise and reflect on our process.

NEXT LESSON

We will use our prioritized criteria, arguments and feedback, and what we know about how fuels release energy to propose a transportation design solution that will minimize negative environmental impacts. We will close out our DQB and reflect on our progress over the last few lessons via the STAMP protocol. Finally, we will reflect on how our Community Agreements have helped us to make progress throughout the chemistry course.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1



WHAT STUDENTS WILL DO

14.A Analyze data using quantitative tools to evaluate future transportation options that satisfy requirements set by society, by using numerical patterns in evidence from radar charts and cost-benefit calculations. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

14.B Develop an argument for the best future transportation options that satisfy requirements set by society, by using numerical patterns in evidence and feedback from peers to refine arguments. (SEP: 6.5, 7.3; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

WHAT STUDENTS WILL FIGURE OUT

- Radar charts can be used to help visualize complex data sets. This allows for better comparison and ability to find patterns in data.
- Quantifying data into positive and negative values can help us to clearly compare the costs and benefits of using certain transportation options over others.
- Making decisions is a multistep process and is influenced by our individual priorities.

Lesson 14 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Have students turn and talk to a partner to remind ourselves of what we figured out last class.	A	
2	5 min		**THINK ABOUT OUR VALUES** Give students time to think, write, and then discuss what types of things influence their values.	B-C	
3	3 min		**RATE IMPORTANCE OF CRITERIA** Have students rate the criteria used to evaluate solutions based on their personal values and their group's transportation goal.	D	
4	19 min		**NARROW OUR LIST OF FUTURE TRANSPORTATION OPTIONS** Have students identify which fuels or transportation solutions will most likely be used in the future. Lead a Consensus Discussion to narrow down the number of options to evaluate for each transportation goal.	E-G	2 prepared sets of *Transportation Options*, Consensus Decision Matrix poster
5	15 min		**EVALUATE TRANSPORTATION OPTIONS USING DECISION MATRIX** Have groups evaluate their top 5 transportation options first for a single criterion, then for the remaining criteria. Show students how to use https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy to record their evaluations.	H-K	internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy, *Transportation Options*, Consensus Decision Matrix poster
					End of day 1
6	7 min		**EVALUATE REMAINING OPTIONS USING DECISION MATRIX** Have students complete evaluating their top 5 transportation options for the remaining criteria.	L	internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy, *Transportation Options*, Consensus Decision Matrix poster
7	10 min		**EVALUATE OPTIONS USING RADAR CHARTS** Lead a class discussion about the visualization of data by examining radar charts. Have students interpret radar charts of their top 5 options based on their group's ratings.	M-N	internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy
8	15 min		**CONDUCT COST-BENEFIT ANALYSIS** Support students in combining their decision matrix evaluations and prioritizations in a cost-benefit analysis.	O-T	*Cost-Benefit Analysis*
9	13 min		**DEVELOP ARGUMENT FOR THE BEST OPTIONS** Have students draft an argument for what they see as the best options for their transportation solution.	U-V	*Transportation Arguments Draft*, internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy
					End of day 2

Part	Duration		Summary	Slide	Materials
10	5 min		**PREPARE TO SHARE ARGUMENTS** Revisit the Community Agreements to identify which agreements we need to adhere to when discussing our arguments with our peers.	W	Community Agreements
11	25 min		**SHARE ARGUMENTS WITH PEERS** Explain the Stand Up-Hand Up-Pair Up protocol. Have students share their arguments with three peers.	X	*Transportation Arguments Draft*
12	12 min		**USE FEEDBACK TO REVISE ARGUMENTS** Have students complete *Transportation Arguments Draft*.	Y-Z	*Transportation Arguments Draft*
13	3 min		**INTRODUCE HOME LEARNING** Introduce the need for additional feedback from a trusted adult to motivate Home Learning.	AA	*Transportation Arguments Draft*

End of day 3

Lesson 14 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Cost-Benefit Analysis* • *Transportation Arguments Draft* • internet-connected device • https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy	• 2 prepared sets of *Transportation Options* • internet-connected device • https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy • *Transportation Options*	• Consensus Decision Matrix poster • https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy • Community Agreements

Materials preparation (30 minutes)

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

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

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

You will need to prepare to conduct a stamp-based feedback protocol throughout this lesson using *STAMP Protocol Matrix*. You will provide TWO stamps for fully-met criteria identified in the Assessment Guidance, ONE for partially-met criteria, and a constructive question when you do not see sufficient evidence.

- You can read more about the STAMP protocol and see an example in *STAMP Assessment Guidance*.

Have the Consensus Decision Matrix poster from Lesson 13 visible.

Print and laminate *Transportation Options* single sided. Cut out the individual tables so that small groups can move them around as they evaluate the transportation options using the consensus decision matrix. You will need two cut-out sets of *Transportation Options* per group.

Create copies of https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy for each class. Students should have editing access so that they can add their group's criteria ratings after coming to consensus. If your class determined subcriteria in Lesson 13 to evaluate, edit the titles of the criteria in the spreadsheet to include those subcriteria.

- A completed example of the radar charts can be previewed at https://docs.google.com/spreadsheets/d/1p2RiU4nJslW_dLksEKglVTzilsyK4mq0I4b6I5-C1I4/edit#gid=1001683799.
- Be sure to watch https://youtu.be/UCXlcWd6iPs for troubleshooting in setting up the radar charts for analysis using the consensus decision matrix. This is particularly important if students came up with categories of criteria and constraints in Lesson 13 that are different from those in the spreadsheet.

Lesson 14 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS3.A.2 Natural Resources**: All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.
- **ETS1.A.1 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.

Students narrow down the number of transportation options to evaluate. In small groups, they use additional fuel data to develop and add their ratings to a spreadsheet version of the consensus decision matrix, which transforms the data into radar charts (DCI: ETS1.A.1, ESS3.A.2). This builds on work throughout Lesson Sets 2 and 3. Students *use patterns in the radar charts and cost-benefit calculations to evaluate transportation options we should consider to use* the most in the future (SEP: 4.1, 6.5; CCC: 1.4). This is the first time this unit that students have leveraged this particular crosscutting concept element, but they have prior experience from *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.

Students *develop and share arguments* with three other peers. The class identifies which Community Agreements should be used as students discuss their arguments with each other. During these discussions, they are prompted to *ask questions to probe for reasoning and evidence and to challenge ideas and conclusions*. Students also *respectfully respond to their peers' ideas* (SEP: 7.3; DCI: ESS3.A.2). Students use these discussions to revise their arguments and reflect on the decision-making process by considering what criteria/constraints they prioritized (SEP: 6.5, 7.3; DCI: ETS1.A.1).

Pay careful attention to the assessment guidance in these last lessons, as they are the basis for end-of-lesson-set assessments. Assessment opportunities 14.A.2 and 14.B.3 may be tracked using the STAMP protocol described in *STAMP Assessment Guidance* and the teacher clipboard matrix found in *STAMP Protocol Matrix*.

Where We Are NOT Going

In this lesson, students primarily focus on prioritized criteria and constraints in their evaluations of transportation options. They will explain their solutions in full and justify them with ideas about energy flows from earlier in the unit in Lesson 15.

Students are not required to understand the meaning of the Greek letter sigma in the equation provided on *Cost-Benefit Analysis*. Make connections if students are familiar with summation notation from algebra, but otherwise the materials already support students in using the equation for its intended purpose without interpreting all the symbols.

LEARNING PLAN for LESSON 14

1 · NAVIGATE

3 min

MATERIALS: None

Turn and talk with a partner about our last class. Display **slide A**. Ask, *What did we figure out last class about future transportation decisions?* Have students turn and talk with a partner about this prompt. After two minutes, ask for a few volunteers to share their discussion.✱ Look for students to mention the decision matrix, the criteria/constraints, or the subcategories developed in Lesson 13 as tools to evaluate the best options for future transportation decisions.

✱ ATTENDING TO EQUITY

Prompt students to share their partners' ideas. This encourages students to listen carefully. Careful listening improves students' opportunities to practice with science language, especially for emerging multilingual learners.

2 · THINK ABOUT OUR VALUES

5 min

MATERIALS: science notebook

Consider what can influence values. Say, *In Oysters Unit, we designed equitable solutions to the problems of our society. We found out that no solution is perfect, nor does it need to be permanent. Personal and societal values can inform our engineering recommendations, while still staying grounded in evidence and scientific ideas. Let's take a moment to think about how the society we live in impacts our decisions and the implications these decisions have on others.*

Display **slide B**.✱ Give students three minutes to stop and jot about the prompts on the slide:

- *Think about the criteria and constraints and subcategories we generated last time. Do they all feel equally important to you?*
- *How are people affected by decisions related to transportation, and how might that impact the values they hold?*

Then have students share their ideas with a partner.
Share what influences our values. Display **slide C.** Now that students have had time to think individually and with a partner, briefly discuss the prompts as a class.

Suggested prompt	Sample student response
Think about the criteria and constraints and subcategories we generated last time. Do they all feel equally important to you?	Yes, because... No, because...
How are people affected by decisions related to transportation, and how might that impact the values they hold?	People might have to start relying on a different fuel source that they don't currently have access to. People might have to buy new vehicles. People might care more about things they see affecting them or affecting places, creatures, and communities that are important to them.

✱ ATTENDING TO EQUITY

Building classroom culture: It is important to organize activities in ways that create opportunities for students to engage in meaningful, accountable talk by emphasizing socially safe activity structures (e.g., small-group or partner work before a whole-class discussion). This is especially beneficial to multilingual students. For this reason, individual time, partner talk, or small-group talk should precede whole-group discussion whenever possible to give students an opportunity to share their ideas with one or two peers before going public with the whole class.

Suggested prompt	Sample student response
How are other parts of the Earth system affected by transportation decisions? How might that influence values?	There will be less CO_2 in the atmosphere. It will affect the entire planet and its habitability for everyone--including living things that aren't people. Some people might be more directly impacted by, or care more about, these effects.

If these ideas do not come up, emphasize that everyone matters as we consider how to address this problem, and it is important to take into account those who are most harmed by the current system when making decisions. A global problem does not require a singular, all-encompassing global solution. Emphasize that the sum of regional and community actions may still make incremental progress toward solving a global problem.

3 · RATE IMPORTANCE OF CRITERIA

3 min

MATERIALS: science notebook

Rate categories of criteria based on personal values. Display **slide D**. Have students identify which of the categories of criteria they see as more or less important to consider when examining transportation solutions. Have students refer to what was discussed in the previous step to help them rate these criteria, with a high value of 5 for what each individual student considers the *most important* and a low value of 1 for what each individual student considers the *least important.* Remind students to record these ratings in their notebooks, as they will refer back to these ideas on day 2 of this lesson.

To help students understand how to rate the categories of criteria, give examples of how one's personal values may factor into which criteria they prioritize over others. Remind students to do this independently, because the goal is for each student to identify how their personal values inform their own ratings and priorities.

ADDITIONAL GUIDANCE	A similar activity was done as a class in a Consensus Discussion in Lesson 12. If you taught that lesson, please refer back to that moment to help explain the goal of this activity. You are also welcome to spend less time having students individually rate the importance of criteria, as they already may be familiar with the idea of factoring their personal values into which criteria they want to prioritize.

4 · NARROW OUR LIST OF FUTURE TRANSPORTATION OPTIONS

19 min

MATERIALS: 2 prepared sets of *Transportation Options*, Consensus Decision Matrix poster

Re-emphasize the Avoid, Shift, Improve engineering framework. Remind students of the Avoid, Shift, Improve framework used throughout the unit. Display **slide E**. Have students consider the prompt: Why do we need to address all three ideas in our engineering design process when considering transportation solutions?

Then ask for a few volunteers to share. Listen for ideas such as:

- A lot of positive change can happen when we simply avoid using fuel-based transportation when it is not absolutely necessary, like we discussed in our last lesson.
- Improving technology or fuel is just one strategy to make transportation better.
- Shifting our use of transportation depending on our goals can help a lot and be simpler than just creating new things.
- Shifting toward the use of transportation methods or fuels can be an easier, gradual step compared to an immediate change.

Motivate narrowing down the list of transportation options. Say, *Last lesson we developed a consensus decision matrix to evaluate transportation options to determine which ones would be best to use in the future. We have considered so many options over the course of the unit that it would be difficult to try to evaluate each one with our decision matrix. Let's narrow it down a bit.*

Narrow down the list of future transportation options. Display **slide F** and say, *I want you to individually look over these transportation option slips and attempt to pick the top 5 you think your group should use for your transportation goal. We will use this information to narrow down our choices for some "finalists."* Read over the directions on the slide and ask if students have any clarifying questions. Organize students into their small groups and distribute two cut-out sets of *Transportation Options* per group to randomly distribute among themselves. Give students 8-10 minutes to individually choose their top 5 options out of the slips they have. Then, display **slide G**. Have students work with their small group for about 7 minutes to come to consensus about their top 5 transportation options.

ADDITIONAL GUIDANCE

Students should recognize the overwhelming nature of evaluating all options using the 5-point decision matrix. The goal of this Consensus Discussion is to narrow down the list to something more manageable to evaluate. Your students may choose other options than those listed in the last bullet below, and that is OK. If groups cannot agree, there will be space to evaluate up to 6 transportation options in the radar charts.

Listen for these ideas about options we should consider:

- Transportation options need to provide high energy released with low carbon emissions.
- Impacts of fuels' extraction, availability, and use will likely determine which transportation options may be used most in the future.
- Non-fuel options are more or less likely to be used depending on the feasibility of implementing them safely with existing infrastructure.
- Options will most likely include: biodiesel, lithium batteries, ethanol, public transportation, or hydrogen. A group may have a different list depending on their particular transportation goal.

5 · EVALUATE TRANSPORTATION OPTIONS USING DECISION MATRIX

15 min

MATERIALS: science notebook, internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy, *Transportation Options*, Consensus Decision Matrix poster

Evaluate options using financial cost information. Have groups keep their top 5 transportation options from *Transportation Options* visible on their table and put away the remaining slips. Point out that even within each group's top options, there still may be debate among students about which solutions are the best. Mention that quantifying the evidence from the transportation option slips by using ratings can help with this.

Display **slide H.** As a class, choose a transportation option that no groups have in their top 5 to demonstrate the rating method. Instruct students to decide on a rating for this sample option and its ability to "move things short distances," based on the criterion of financial cost. The rating should be from -2 to 2, with zero as the "middle" number.✱ Remind students that a rating assigned to the option with a less optimal financial cost should be negative, even though that corresponds to a higher cost.✱

Introduce Transportation Solution Decision Matrix spreadsheet. Once the class has decided on a rating for the sample option, suggest that it might be helpful to keep all the groups' work in one place so that we can easily compare our evaluations. Display **slide I**. Have a member of each group access the class copy of https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy and claim a tab on the bottom of the spreadsheet for their group to use, that corresponds to the group's transportation goal. Say, *One output of our spreadsheet will be a radar chart like the one on the slide. ✱ This will help us visualize our ratings for each criterion so we can compare the transportation options using all five categories of criteria and constraints.*

Demonstrate how to input a rating for financial cost for the sample transportation option. (Enter the value in column C of the color-coded data table.) Point out how this changes the display of the corresponding radar chart. Ask students if they have any clarifying questions.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

While not assessed in this lesson, students use mathematical reasoning related to *scale, proportion, and quantity* to think about ratings. What is important is that students are able to explain their *mathematical reasoning using reasoning about how the number "matches" the qualitative information*.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Representation. You can *vary the cognitive demand* here to more deeply engage with scale. If students want to better understand

ADDITIONAL GUIDANCE

If you are having difficulty with the spreadsheet, you can see some tips and tricks for using radar charts in Google Sheets in this video guide: https://youtu.be/UCXlcWd6iPs

A completed, worked example of these radar charts is available at https://docs.google.com/spreadsheets/d/1p2RiU4nJslW_dLksEKglVTzilsyK4mq0I4b6I5-C1I4/edit#gid=1001683799.

Rate our transportation options on financial cost, using evidence. Display **slide J.** Give groups five minutes to rate their top 5 options on financial cost, just as they did as a class with the sample option, using the information provided on *Transportation Options*. Remind students to refer back to the subcategories they developed in Lesson 13. Ensure that one student in each group is adding their group's ratings and reasoning to the spreadsheet, and that all students are recording the ratings and reasoning for each transportation option in their notebooks. Move around the room to support students with the use of the rating scale and the Decision Matrix spreadsheet.

Rate transportation options on the remaining criteria, using evidence. Prompt students to attend to how much data has been generated, even with just the financial cost ratings. It is a lot of data! Use this to motivate the importance of keeping track of all their ratings in the Decision Matrix spreadsheet as well as students' notebooks throughout this process. Display **slide K.** Give groups the remainder of the class period to rate their transportation options on the remaining four categories of criteria (energy released, safety, environment, and infrastructure) using the information provided on *Transportation Options*. Ensure that one student in each group is adding their group's ratings and reasoning to the spreadsheet, and that all students are recording the ratings and reasoning for each transportation option in their notebooks. Tell students there will also be a little time at the beginning of the next class to continue rating anything that was not finished in class today.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students quantify the value of transportation solutions based on their ability to satisfy various requirements set by society. (DCI: ETS1.A.1, ESS3.A.2)
- Students use mathematical representations in their quantitative tools to track patterns in their data. (SEP: 4.1; CCC: 1.4)

What to do: As groups work, move around the room and listen in on their discussion for at least one full minute at a time. A lively discussion with some debate within groups is a sign that students are deeply engaged.

Listen for reasoning that leverages the data on *Transportation Options*. If students are quantifying each transportation option without using the data, ask, *What information are you looking at to help determine your ratings?* If students are not recording their reasoning in the spreadsheet or notebooks, remind them to do so.

If students are discussing without quantifying the options based on the criteria and constraints, prompt them to consider whether the transportation solution is more or less optimal for that particular criterion or constraint. Then remind students of the numerical relationship established on **slide H** to elicit a numerical value.

Building toward 14.A.1 Analyze data using quantitative tools to evaluate future transportation options that satisfy requirements set by society, by using numerical patterns in evidence from radar charts and cost-benefit calculations. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

End of day 1

the use of a scale from -2 to 2, you are welcome to have them consider reasons why it would be more useful in a quantitative analysis than a scale from 1 to 5. You may also point out the need for numerical ratings as a comparison tool. (CCC: 3.5)

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

The spreadsheet is set up to create radar charts using a 5-point rating scheme that students determine. This helps students later in the lesson as they *use this mathematical representation of the decision matrix* to *support the development of a claim* around which transportation options we should consider most for future use. (SEP: 5.2)

6 · EVALUATE REMAINING OPTIONS USING DECISION MATRIX

7 min

MATERIALS: science notebook, internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy, *Transportation Options*, Consensus Decision Matrix poster

Rate transportation options on any remaining criteria, using evidence. Display **slide L.** Give groups five additional minutes to continue where they left off the previous class: rating their options on the remaining four categories of criteria (energy released, safety, environment, and infrastructure) using the information provided on *Transportation Options*. Ensure that one student in each group is adding their group's ratings and reasoning to the spreadsheet, and that all students are recording the ratings and reasoning for each transportation option in their notebooks. See the Assessment Guidance from the end of day 1.

7 · EVALUATE OPTIONS USING RADAR CHARTS

10 min

MATERIALS: science notebook, internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy

Make sense of radar charts. Say, *Let's use the radar charts to start to make sense of our class's evaluations of the transportation options.* Display **slide M** and have students consider the prompts on the slide. Display examples of radar charts from https://docs.google.com/spreadsheets/d/1p2RiU4nJslW_dLksEKglVTzilsyK4mq0I4b6I5-C1I4/edit#gid=1001683799 to support students' thinking.

Suggested prompt	Sample student response
How does comparing radar charts help us evaluate the transportation options?	We can see all the criteria evaluated together.
What do we expect to see on the radar chart for an option that was highly rated overall?	The bigger the shape's area, the better the solution is overall. There can be exceptions with non-fuel options because those have no energy released data. Most radar charts have different high points and low points to make irregular shapes.

Have students interpret radar charts for their top options. Display **slide N**. Have students work in groups to record observations in their notebooks about the radar charts they generated. Then, remind them to use those observations to support their interpretations of the data. Give students three minutes to work in their groups and take two minutes to have students share some of their interpretations with the class.

Problematize the limitations of the radar charts. Ask, *In thinking about the different criteria on the radar charts, did you incorporate the rankings you made earlier in the lesson? Do the radar charts' sizes fully reflect your values and decision-making?* It is OK for the class to disagree; it is important that students are reflecting on their own values here.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use mathematical representations in their quantitative tools to track patterns in their data. (SEP: 4.1; CCC: 1.4)
- Students use numerical data from quantitative tools to evaluate which options are best to use in the future. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2)

What to do: When students work in their groups, walk around the room to notice the main observations students make of their radar charts. Put TWO stamps on *STAMP Protocol Matrix* if students have accomplished both of these look-fors completely. Put ONE stamp on *STAMP Protocol Matrix* if students have accomplished one of the look-fors, and NO stamps if they have not accomplished either of them. If students do not get two stamps, leverage any ideas that build toward the following:

- Students notice that higher ratings create larger shapes.
- Students associate larger shapes with better transportation options because they satisfy more of the criteria and constraints.
- Students notice that the charts with inconsistent, "irregular" shapes (lots of sharp angles and variable ratings) represent transportation options that have both benefits and drawbacks.

If students are only discussing patterns in the shapes without assigning meaning to them, prompt students to consider how inputting different values (from -2 to +2) into https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy changed the output shape in the radar chart. Then prompt them to connect the shape generated with the ratings that were inputted so that students articulate the relationship.

Some students may consider the ratings without referring much to the shapes generated by the radar charts when evaluating the transportation options. That is fine, as long as they are able to articulate how the scale used in the ratings and radar charts quantifies each option's merits and limitations within the various criteria and constraints.

Building toward 14.A.2 Analyze data using quantitative tools to evaluate future transportation options that satisfy requirements set by society, by using numerical patterns in evidence from radar charts and cost-benefit calculations. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

ADDITIONAL GUIDANCE

Radar charts are a useful tool to quickly see how an option "measures up" on various criteria, but they do not capture relative importance of criteria. Cost-benefit analyses are intended to do that. After their introduction here, they will be used further in OpenSciEd Physics in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*. Note that although cost-benefit analysis allows students to prioritize criteria based on their values, it is only one tool used in decision-making. Cost-benefit analysis represents a particular Western-influenced perspective, with its emphasis on quantification, and does not capture complexities and interrelationships as well as some non-Western decision-making tools and strategies.

8 · CONDUCT COST-BENEFIT ANALYSIS

15 min

MATERIALS: *Cost-Benefit Analysis*, science notebook

Introduce the idea of a cost-benefit analysis. Display **slide O.** State the definition of a cost-benefit analysis. Explain that we will be giving positive values to "benefits" and negative values to "costs" to calculate a total sum that will help us identify whether or not a solution is beneficial overall. Organize students into their small groups and distribute *Cost-Benefit Analysis*.✱

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND

Have students select one transportation option to analyze first. Give each group two minutes to complete Step 1 on *Cost-Benefit Analysis*. This consists of recording their top 5 transportation options in the title of each Calculation Table. Have groups choose one of the options to start analyzing for now, before jumping into all five.

Factor in personal ratings of criteria. Display **slide P**. Give students two minutes to complete Step 2 as outlined on *Cost-Benefit Analysis* on their own. They will need to revisit their individual ratings of criteria based on their personal values, from the previous day.

Input group ratings of criteria. Display **slide Q**. Give each group three minutes to complete Steps 3 and 4 as outlined on *Cost-Benefit Analysis*. Students will record their group's criteria ratings from the Decision Matrix spreadsheet and then individually multiply those ratings by their personal values ratings.

Demonstrate a cost-benefit analysis calculation. Explain that the overall analysis will differ among students in the same group, based on the individual students' values ratings of the criteria. Use the example calculation on **slide R** to show how to complete Step 5 on *Cost-Benefit Analysis*. Students will see the same sample calculation on the handout.

Have students complete cost-benefit analyses for their group's top five transportation options. Display **slide S**. Give students three minutes to complete the cost-benefit analysis for their first transportation option on *Cost-Benefit Analysis*. Remind them that their personal values ratings are also factored into each criterion and constraint. Encourage students to have the teacher or a peer check their work before completing a cost-benefit analysis for their next transportation option. Display **slide T** when all students have successfully completed one cost-benefit analysis calculation so they know to move on to the Calculation Tables for their remaining transportation options.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students quantify the value of transportation solutions based on their ability to satisfy various requirements set by society. (DCI: ETS1.A.1, ESS3.A.2)
- Students use mathematical representations in their quantitative tools to track patterns in their data. (SEP: 4.1; CCC: 1.4)
- Students use numerical data from quantitative tools to evaluate which options are best to use in the future. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2)

What to do: Push students to focus on missing elements of these look-fors or on what students learned as a result of their conversations with peers. Use the following guiding questions to evaluate the qualities of their arguments:

- How have students quantified the value of each transportation option included in their analysis?
- How are students tracking their patterns with the cost-benefit analysis tables?
- How do students interpret the numerical data they have generated during the lesson to evaluate the options?

If you cannot visit all students in the time allotted, post the questions and have students self-assess their progress.

Building toward 14.A.3 Analyze data using quantitative tools to evaluate future transportation options that satisfy requirements set by society, by using numerical patterns in evidence from radar charts and cost-benefit calculations. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

INTERPRETING DATA

In this part of the lesson, students analyze data to identify characteristics of the components of a proposed transportation option to optimize it relative to criteria for success, especially carbon reductions. (SEP: 4.6)

9 · DEVELOP ARGUMENT FOR THE BEST OPTIONS

13 min

MATERIALS: science notebook, *Transportation Arguments Draft*, internet-connected device, https://docs.google.com/spreadsheets/d/1qu8QZgKKMkPO9v8HZTYck4tAvvez-g5BA9P7UA-C95A/copy

Discuss analyses in groups. Display **slide U**. Have students consider the prompts on the slide and discuss them in their groups. If you would like, allow for some volunteers to share their ideas with the class.

Suggested prompt	Sample student response
How did the cost-benefit analysis help identify which transportation options had the most potential? the least potential?	Calculating to see if the positives outweigh the negatives made it easier to come to a definite answer of whether it is a "good" or "bad" option. Large, positive numbers had the greatest potential. Negative numbers with a large absolute value had the least potential.
Why might each individual have different cost-benefit analyses even with the same criteria ratings and radar charts?	It factored in our personal values, so if another student valued a different category of criteria more, then that would have a bigger impact on the result if it was a positive or negative aspect of that solution.

Have students prepare individual drafts to argue for what they see as the best options for their transportation solution. Display **slide V**. Say, *Now that we have had a chance to discuss our ratings using the radar charts and cost-benefit analyses, I want you to individually identify which transportation options we should consider to be the best solutions for the future.*

Distribute *Transportation Arguments Draft* and give students the remaining class time to complete Part 1.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students support their arguments using patterns they observe from evidence. (SEP: 7.3; CCC: 1.4)
- Students articulate how they prioritized the requirements set by society based on their personal values and the impacts of that prioritization on their decision. (SEP: 6.5; DCI: ETS1.A.1)

What to do: Walk around the room to observe what students are drafting. Encourage students to articulate their argument with you in individual conversations to get an idea of what they are thinking.

Look for students to accomplish the first look-for as they develop their argument. Then look for students to accomplish the second look-for as they respond to the follow-up questions in Part 1.

Remember, it is not required that students have consensus among groups or one another.

Building toward 14.B.1 Develop an argument for the best future transportation options that satisfy requirements set by society, by using numerical patterns in evidence and feedback from peers to refine arguments. (SEP: 6.5, 7.3; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

10 · PREPARE TO SHARE ARGUMENTS

5 min

MATERIALS: Community Agreements

Revisit the Community Agreements. Have the Community Agreements visible. Say, *In a minute you will share your arguments with a few of your classmates. You may not have come to the same conclusions, so let's take a moment to remind ourselves of our Community Agreements.*

Display **slide W**. Say, *Look over the Community Agreements. Which agreement should we make sure we are following when sharing and discussing our arguments for transportation options?* Accept all student responses and encourage students to show when they agree with their classmates.

Say, *If we are following that Community Agreement, what would respectful disagreement sound like?* ✱ Accept all student responses.

✱ SUPPORTING STUDENTS IN ENGAGING IN ARGUMENT FROM EVIDENCE

In the next step of the lesson, students meet and discuss their arguments with 2-3 peers. Emphasizing how to *respectfully provide and receive critiques on their scientific arguments* will help students as they engage with this science and engineering practice. Point out that students should *ask questions to probe for reasoning and evidence, challenge ideas and conclusions, and respond thoughtfully to other perspectives*. (SEP: 7.3)

11 · SHARE ARGUMENTS WITH PEERS

25 min

MATERIALS: *Transportation Arguments Draft*

Explain the Stand Up-Hand Up-Pair Up protocol. Display **slide X**. Talk through the slide to explain the protocol students will use to share their arguments. Explain that they will have six minutes in each pair: one minute for Person 1 to share their ratings, one minute for Person 2 to repeat ideas and ask questions, and one minute for Person 1 to respond to Person 2. Then pairs switch roles and repeat the process. Ask students if they have any clarifying questions before starting the activity. Use a one-minute timer to help students stay on track.

Have students repeat this two more times so that they meet with a total of three peers. As students discuss their arguments, move around the room and listen to the conversations. This will provide you with additional valuable information when assessing students using the STAMP protocol described in *STAMP Assessment Guidance*, when they turn in *Transportation Arguments Draft* at the end of the lesson. Tell students you will be listening to these conversations to gather information that will help you with the STAMP protocol when they revise or refine their arguments.

COLLABORATION



This may be an opportunity to have students choose a focal Community Agreement to attend to while they are working in their groups. You may also have students choose a sentence starter that will help guide their interactions with their peers. (See "Routines and Tools to Support Peer Assessment" from the *OpenSciEd High School Teacher Handbook*.)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students support their arguments using patterns they observe from evidence. (SEP: 7.3; CCC: 1.4)
- Students articulate how they prioritized the requirements set by society based on their personal values and the impacts of that prioritization on their decision. (SEP: 6.5; DCI: ETS1.A.1)
- Students respectfully pose clarifying questions to respond to diverse perspectives, probe for reasoning and evidence, and challenge ideas or conclusions to evaluate the strength of peers' arguments. (SEP: 7.3)

What to do: Move around the room and listen in on discussions for at least one full minute at a time. If possible, jot notes or keep track of what you hear in these discussions as it may help with the STAMP protocol at the end of the lesson. Use the following guiding questions to evaluate the qualities of students' arguments:

- How are students using patterns?
- How are students using data in their arguments?
- How are students using evidence to connect their argument to their claim?
- How are students considering the various criteria and constraints in their reasoning?

Use the following guiding questions to evaluate students' engagement with peers:

- Are students asking questions in an attempt to understand each other's thinking?
- Are students following the Community Agreements? (Intervene to provide feedback on this if necessary.)

If students struggle to pose questions to their peers, support them by providing question stems such as:

- What pieces of evidence helped you come to that conclusion?
- How did the radar charts inform your argument?
- What pattern are you focusing on?
- What is the main claim you are making about future transportation solutions?

Building toward 14.B.2 Develop an argument for the best future transportation options that satisfy requirements set by society, by using numerical patterns in evidence and feedback from peers to refine arguments. (SEP: 6.5, 7.3; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

12 · USE FEEDBACK TO REVISE ARGUMENTS

12 min

MATERIALS: *Transportation Arguments Draft*

Consult with small groups on feedback received during the Stand up-Hand up-Pair up protocol. Display **slide Y**. Have students consider the prompt on the slide and discuss in their small groups for about five minutes. The goal is to have students with the same transportation goal reflect on feedback from peers they may not have interacted with during the previous activity.

Reflect on peer discussions to revise arguments. Display **slide Z**. Give students about seven minutes to complete Parts 2 and 3 of *Transportation Arguments Draft*, which ask students to revise their arguments and reflect on their interactions with peers. ✱ Tell students that you will conduct the final STAMP protocol check for this lesson and encourage them to record how many stamps they earn on *Transportation Arguments Draft*. As students work to complete Parts 2 and 3, conduct the STAMP protocol for this lesson using *STAMP Protocol Matrix*.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Parts 2 and 3 of *Transportation Arguments Draft* provide opportunities to support students' *engagement* through self-regulation by incorporating prompts that encourage both self-assessment and reflection during argumentation with data (SEP: 4.6). Ensure that students are given adequate time to complete these questions. It is important to give students this space and time as a way to

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students support their arguments using patterns they observe from evidence. (SEP: 7.3; CCC: 1.4)
- Students articulate how they prioritized the requirements set by society based on their personal values and the impacts of that prioritization on their decision. (SEP: 6.5; DCI: ETS1.A.1)
- Students revise and/or refine their arguments for the best future transportation options. (SEP: 7.3; DCI: ESS3.A.2)

What to do: Walk around the room and put TWO stamps on *STAMP Protocol Matrix* if students have accomplished all three of these look-fors completely. Put ONE stamp on *STAMP Protocol Matrix* if students have accomplished one or two of the look-fors, and NO stamps if they have not accomplished any of them. If students do not get two stamps, push them to focus on missing elements of the look-fors or on what they learned as a result of their conversations with peers. Use the following guiding questions to evaluate the qualities of their arguments:

- How are students using patterns?
- How are students using data in their arguments?
- How are students using evidence to connect their argument to their claim?
- How are students considering the various criteria and constraints in their reasoning?
- How are students using each other's clarifying questions and feedback to revise or refine their arguments?

You may use information gathered during the previous assessment opportunity to support your assignment of stamps.

If you cannot visit all students in the time allotted, have them turn in their handouts on their way out of the classroom and return these to students the following day.

Building toward 14.B.3 Develop an argument for the best future transportation options that satisfy requirements set by society, by using numerical patterns in evidence and feedback from peers to refine arguments. (SEP: 6.5, 7.3; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)

develop the skills to successfully engage in argumentation with others in and outside of the classroom.

13 · INTRODUCE HOME LEARNING

3 min

MATERIALS: *Transportation Arguments Draft*

Introduce the need for additional feedback from a trusted adult. Display **slide AA**. Remind students that the next lesson is the last lesson of the unit, which culminates in a final product that builds on the arguments they developed and revised today. Say, *We talked to trusted adults at the beginning of the unit to get their perspective on this issue, so it is worthwhile for us to share our arguments with them now and receive their feedback as well.* Emphasize that sharing arguments and getting additional feedback from a trusted adult can help students refine their ideas in preparation for the next lesson.

Additional Lesson 14 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-WRITING.HST.9-10.1.b: Develop claim(s) ~~and counterclaims~~ fairly, supplying data and evidence ~~for each~~ while pointing out the strengths and limitations of ~~both~~ claim(s) ~~and counterclaims~~ in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns. Students develop individual claims about which transportation options they think would be the best to use in the future. They share those claims in small groups and with three other students. Students pose questions to each other evaluating the strengths and limitations of the claims. They individually use this information to revise their claims.

LESSON 15: How can we make transportation decisions to benefit our communities and Earth?

PREVIOUS LESSON

We considered our personal values to prioritize the five categories of criteria/constraints. We evaluated transportation options using radar charts to visualize ratings based on criteria/constraints. We completed cost-benefit calculations that factored in our personal values and ratings. We generated arguments for our top three transportation options. We shared arguments with classmates, then revised and reflected on our process.

THIS LESSON

PUTTING PIECES TOGETHER

2 days



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We use our prioritized criteria, arguments from Lesson 14, and feedback on our arguments to propose a transportation design solution. We use what we have learned about how various fuels release energy to argue for a solution that will minimize negative environmental impacts. We close out our DQB and reflect on our progress over the last few lessons via the STAMP protocol. Finally, we reflect on how our Community Agreements have helped us to make progress throughout the chemistry course.

NEXT LESSON

There is no next lesson.

BUILDING TOWARD NGSS

HS-PS1-4, HS-PS1-8, HS-PS3-1, HS-PS3-2, HS-PS3-5, HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ETS1-1

WHAT STUDENTS WILL DO

15.A Apply knowledge about the costs and benefits of resource extraction and energy and resource use and quantify them to propose vehicle systems or transportation goals designed to reduce carbon emissions and meet prioritized criteria and address trade-offs. (SEP: 6.5; DCI: ETS1.A.1, ETS1.A.2, ESS3.A.2; CCC: 2.3, 5.2)

WHAT STUDENTS WILL FIGURE OUT

- We can combine our chemistry knowledge, engineering decisions, and prioritized criteria to create a final transportation design proposal.
- We can use chemistry and engineering to design transportation solutions that provide the needed energy for transportation while reducing negative environmental impacts.

Lesson 15 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Have partners share the feedback they received on their draft transportation arguments.	A	*Transportation Arguments Draft*
2	20 min		**COMPLETE FINAL DESIGN PROPOSALS** Have students complete the Final Design Proposal	B	*Final Design Proposal*
3	20 min		**REFLECT ON DESIGN PROPOSALS** Have students reflect in groups, then lead a whole-class discussion about the design proposals.	C-E	
					End of day 1
4	7 min		**IDENTIFY QUESTIONS WE HAVE ANSWERED** Have students evaluate DQB questions together using *Our DQB Questions*.	F	*Our DQB Questions*
5	18 min		**CLOSE OUT THE DQB** Have students combine into larger groups to discuss the DQB questions they feel have been answered, then have a whole-class discussion.	G-H	*Our DQB Questions*, DQB
6	20 min		**TAKE STOCK OF OUR PROGRESS AS A SCIENTIFIC COMMUNITY** Facilitate a Scientists Circle to discuss how the Community Agreements helped the class learn together.	I-K	*Transportation Proposal Reflection*, Community Agreements
					End of day 2

Lesson 15 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Transportation Arguments Draft* • *Final Design Proposal* • *Our DQB Questions* • *Transportation Proposal Reflection*		• DQB • Community Agreements

Materials preparation (30 minutes)

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

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

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

You will need to prepare to conduct a stamp-based feedback protocol throughout this lesson using *STAMP Protocol Matrix*. You will provide TWO stamps for fully-met criteria identified in the Assessment Guidance, ONE for partially-met criteria, and a constructive question when you do not see sufficient evidence. See the Assessment Guidance boxes for specific details.

- You can read more about the STAMP protocol and see an example in *STAMP Assessment Guidance*.

You should have already created the handout *Our DQB Questions* for your class in Lesson 8. If a significant number of student questions have been added to the DQB since then, you should create an updated version with those new questions and prepare to distribute that to students in addition to their original copy.

Have the DQB and Community Agreements visible for day 2.

Lesson 15 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS3.A.2 Natural Resources**: All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.
- **ETS1.A.1 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.
- **ETS1.A.2 Defining and Delimiting Engineering Problems**: Humanity faces major global challenges today, such as the need for ~~supplies of clean water and food or for~~ energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

Crossout explanation: Students address issues related to food and water in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. All three elements have been built throughout Lesson Sets 2 and 3.

This lesson is the final lesson in the course. It contains a portfolio assessment that is compiled from the STAMP protocol scores from Lessons 13-15 recorded on *STAMP Protocol Matrix*. A key, *Final Design Key*, is included for the Lesson 15 LLPE and can be translated to stamps on *STAMP Protocol Matrix*.

After receiving feedback on their arguments developed in Lesson 14, students develop a *final design proposal* to identify a transportation solution that best fits the *quantified criteria and constraints* identified in earlier lessons (SEP: 6.5; DCI: ETS1.A.1). Students' proposals specify how proposed solutions are designed to meet transportation energy and resource needs while reducing environmental impacts in their communities and world (SEP: 6.5; DCI: ETS1.A.2, ESS3.A.2; CCC: 2.3, 5.2). The idea that systems can be designed to cause certain effects has been built throughout Lesson Sets 2 and 3. The consideration of energy flows is a return to ideas from Lesson Sets 1 and 2 and is important to ensure that students tie engineering thinking to science ideas.

Students then discuss their proposals with a small group and consider what technologies or policies may be required to help realize their proposals (DCI: ETS1.A.2, ESS3.A.2).

Where We Are NOT Going

Students do not go so far as to present their transportation design proposals to a specific audience beyond the classroom; this is something you can include if time permits.

Stress to students that many small-scale changes do add up and can impact large-scale systems. While *scale, proportion, and quantity* is not a focus of this lesson, students did spend time thinking about scale in Lesson 6 and in earlier units, so that may surface during discussions.

LEARNING PLAN for LESSON 15

1 · NAVIGATE

5 min

MATERIALS: science notebook, *Transportation Arguments Draft*

Navigate. Display **slide A** and have students take out *Transportation Arguments Draft* from last class. Give partners five minutes to discuss the feedback they received from peers and trusted adults on their chosen transportation goal or solution from Lesson 14. Each student should spend about a minute summarizing their ideas and the feedback they received. Then students should plan how to edit their arguments using this feedback.

2 · COMPLETE FINAL DESIGN PROPOSALS

20 min

MATERIALS: science notebook, *Final Design Proposal*

Finalize design proposals. Display **slide B**. Say, *We have spent a lot of time thinking about trade-offs, our values, and impacts on others, as well as evaluating possible ways to improve our relationship with transportation. Now it is time to put it all together. You will create a final design proposal for a transportation goal or option that you believe is the most important or impactful.* Distribute *Final Design Proposal*. Let students know that they can use any materials from the unit to help support the development of their design proposals. ✱ As students work to complete *Final Design Proposal*, conduct the final STAMP protocol check for Lesson 15 on *STAMP Protocol Matrix*, using *Final Design Key* for guidance. Let students know that this will be the final STAMP protocol evaluation you will conduct.
If students need more time to finalize their design proposal, you could have them turn in what they have, provide them feedback on this, and then allow them to complete their proposal outside of class. Be sure to collect *Final Design Proposal* from all students.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students propose a specific design solution for future transportation and discuss potential benefits and risks. (SEP: 6.5; DCI: ESS3.A.2)
- Students' proposed vehicle or transportation systems are designed to help minimize environmental impacts. (DCI: ETS1.A.2; CCC: 2.3)
- Students' design solutions quantify how they meet the specified considerations. (SEP: 6.5; DCI: ETS1.A.1)
- Students' proposed vehicle or transportation systems leverage energy and matter flows while minimizing negative environmental impacts. (DCI: ETS1.A.2; CCC: 5.2)

What to do: See *Final Design Key* for guidance on how to complete the STAMP protocol for this assessment moment. You may collect students' work and provide feedback asynchronously, or use stamps to provide immediate feedback to students about their progress and your expectations for revision.

Building toward 15.A Apply knowledge about the costs and benefits of resource extraction and energy and resource use and quantify them to propose vehicle systems or transportation goals designed to reduce carbon emissions and meet prioritized criteria and address trade-offs. (SEP: 6.5; DCI: ETS1.A.1, ETS1.A.2, ESS3.A.2; CCC: 2.3, 5.2)

ALTERNATE ACTIVITY

If you feel students already have fully fleshed out their thinking around their own design proposals, you may instead ask them to apply the decision matrix to a current proposal for transportation in their community or region.

✱ SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Students support their design proposals by including *evidence* and identifying the *prioritized criteria* they used to *evaluate* transportation options and address a real-world problem, which leads to the claim students make about transportation design. Information on how to assess students' use of SEP 6.5 is included in the *Design Proposal Rubric*.

3 · REFLECT ON DESIGN PROPOSALS

20 min

MATERIALS: None

Reflect on final design proposals. Display **slide C.** Say, *We have figured out a lot of the chemistry behind how our vehicles work. We have also used engineering ideas, such as criteria, constraints, and trade-offs, to help us think about solutions.* Push students to consider whether science and engineering alone helped them make their decisions about transportation solutions.

Suggested prompts	Sample student responses	Follow-up questions
What science and engineering ideas that we have discussed did you use to make your decisions?	We used what we knew about different fuels and how they provide energy. We considered fuels that produce less or no CO_2 and how they provide energy. We considered various criteria and constraints.	*What else went into your decision-making?*
How did your values or the values of your community influence your decision-making?	I thought environmental impact was really important, so I pushed for a solution even though it may have a high cost. I was really concerned with safety, so I made my decision based on what seemed safest.	*How might someone with different values come to make different decisions?*

Consider how we might get from our current transportation systems to those that students proposed. Say, *Many, if not all, of your proposed solutions look very different from today's transportation systems. I want you to consider these gaps.* Give students about seven minutes to discuss the prompts on **slide D** in small groups. Tell students that since there are at least some differences between most students' proposals, they should make sure that each group member has the opportunity to answer each question on the slide.

Discuss differences between the present and future as a class. After groups have had time to discuss all of the prompts, call the class back together and display **slide E**. Student responses may vary widely depending on their specific proposals, but listen for students to say that we are producing far more carbon dioxide now than we should in the future.

- What is different between where we are now and your proposed future?
- What changes--individual, institutional, and systemic--need to occur to get where we want to be?
- What role could we play in making those changes happen?

KEY IDEAS

Purpose of this discussion: To help students recognize next steps to make their proposals reality and recognize roles they can take in making them happen.

Listen for these ideas:

- We may need laws to help implement the changes we are proposing.
- We may need large-scale changes to cities and infrastructure to make them safer for walking, biking, or public transportation.
- We could become engineers and develop new solutions, advocate for policy changes, or make choices in our own lives that reflect our vision.

Say, *Now that we have proposed various solutions to improve transportation systems, are we done? Have we answered all of the questions that we had at the beginning of this unit?* There may be some disagreement among students as to whether or not all questions have been answered. Suggest going back to the DQB for a final check of our questions.

End of day 1

4 · IDENTIFY QUESTIONS WE HAVE ANSWERED

7 min

MATERIALS: *Our DQB Questions*

Return to the DQB. Display **slide F**. Read through the directions on *Our DQB Questions* to remind students how to evaluate DQB questions. Have students update *Our DQB Questions* in pairs. Once they have marked which questions have been partially answered or completely answered, each student can choose one or two questions to write brief answers for. This will prepare them for the next step, where they will meet with other students to form a larger discussion group.

5 · CLOSE OUT THE DQB

18 min

MATERIALS: science notebook, *Our DQB Questions*, DQB

Discuss DQB questions in groups. Display **slide G**. Have pairs from the previous step join together into groups of four. Each pair should pick a spokesperson, and pairs should spend about four minutes sharing the questions they have answered with each other. After four minutes, have two groups of four join together to make a group of eight and repeat this process. A spokesperson for each group should share which questions they have answered.

After another four minutes of discussion in the larger groups, call the class back together. Start by asking students what proportion of questions they feel we at least partially answered based on the rounds of discussion they just completed--students should count all of the check marks and check-pluses they put on their paper and compare that tally to the total number of questions on *Our DQB Questions*.

Spend a few minutes having students share some example questions that they feel we made progress on. Encourage nonverbal participation as well, such as thumbs up, thumbs down, and thumbs sideways to indicate agreement or disagreement. Then ask for a volunteer to choose one of the questions they feel the class fully answered and to share their answer. Encourage other students to build on the first student's answer or ask follow-up questions. Spend a few minutes discussing one or two more fully-answered questions, then do the same for a few partially-answered questions.

ADDITIONAL GUIDANCE

Encourage students to opt for the "obvious" questions here, or the ones you and the students are confident have been answered, as you will discuss the more daunting questions on the next slide. It may help to prompt this discussion by asking:

- *What was the first thing we figured out?*
- *What questions do we feel we have completely answered?*

Celebrate accomplishing difficult tasks in this unit. Next, ask students to identify a few questions that seemed insurmountable or challenging at the start of the unit and discuss why they seemed so challenging then. Display **slide H**. Repeat the process from the previous step: Ask for a volunteer to identify a question from the DQB that seemed daunting at the beginning of the unit but that the class eventually answered. After a question has been identified, discuss what the class did to answer the question and what we figured out. Encourage students to continue to use nonverbal signals to agree and disagree, and to look around the room to see if their peers agree with them. After repeating this process for another question or two, discuss how the class worked together to figure out these ideas.

6 · TAKE STOCK OF OUR PROGRESS AS A SCIENTIFIC COMMUNITY

20 min

MATERIALS: science notebook, *Transportation Proposal Reflection*, Community Agreements

ADDITIONAL GUIDANCE If this is not your final unit of the chemistry course, save this discussion for the end of your final unit.

Reflect on what we accomplished in this project. Display **slide I**. Say, *Throughout the last three lessons, you have used both chemistry and engineering principles to think about how we can improve transportation systems, and considered how individual and community values can influence how we prioritize criteria. Let's take a moment to reflect on all that you have learned and accomplished over these past few lessons.* Distribute *Transportation Proposal Reflection* and give students five minutes to reflect on their learning independently. When students are done, collect their reflections.✱

Reflect on our Community Agreements. Display **slide J** and gather students in a Scientists Circle. Discuss some of the things we did in our learning community that helped us make progress in this and other units by working together. As students raise examples, ask other students to identify how these exemplify our community commitments. Encourage students to share examples of progress our class made in figuring out how to grow together as a learning community over the year.

Suggested prompt	Sample student response
How did we work together as a community to make progress on our questions?	We planned investigations together. We did a lot of thinking and working in groups and we helped each other. We gave feedback on each other's ideas.
How have our Community Agreements helped us learn together this year?	They helped us be accountable to each other and to respect each other and each other's ideas. They reminded us to listen to each other and make space for lots of voices and ideas.

Celebrate all we have figured out this course. Stay in the Scientists Circle and discuss the prompts on **slide K**.

Suggested prompt	Sample student response
What problems, both local and global, have we investigated this year?	Melting polar ice and rising sea levels. Ocean acidification due to carbon dioxide. How to stay safe when there is lightning. Transportation-related carbon emissions.

✱ ATTENDING TO EQUITY

While you do not need to read these reflections with the specific aim of giving a grade, you may find that some students demonstrate learning that you did not give them credit for previously. This reflection is also an opportunity for students to show growth in their awareness of issues of social and environmental justice or in their understanding of how science connects to issues of justice in their community and world.

Suggested prompt	Sample student response
How can chemistry and engineering help us address those problems?	We can use chemistry and engineering to design solutions to specific problems. We used chemistry to think about how to address ocean acidification and climate change. We used chemistry and engineering to think about solutions to polar ice melt and sea-level rise. If we understand the chemistry behind problems, we can figure out the chemistry of solutions.
What else in our lives can we explain or address using ideas we have figured out this year?	Accept all responses.

Foreground optimism for the future. Say, *We really can help solve major global problems--if we continue to push ourselves to engage others in our communities in the kinds of sensemaking and decision-making that we used in this class.*

Additional Lesson 15 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-WRITING.HST.9-10.1.b: Develop claim(s) ~~and counterclaims~~ fairly, supplying data and evidence ~~for each~~ while pointing out the strengths and limitations of ~~both~~ claim(s) ~~and counterclaims~~ in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns.

Students develop an individual claim about the transportation solution they feel would be most impactful in the future and support their claim with evidence from sources gathered throughout the unit.

Unit C.5 Teacher Reference Materials

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the "Assessment Icon" in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial Models	**Pre-Assessment** Students build an initial model in Lesson 1 that serves as a pre-assessment before the unit begins. Students identify changes or transfers of matter, energy, and forces in the vehicle system. Early student models show more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to leverage student ideas across the unit. The initial model developed starting on day 1 of Lesson 1 is a good opportunity to pre-assess student thinking about the key components in a vehicle, their understanding of how energy transfers through the vehicle system, and locations where forces are acting within the vehicle system. It is unlikely that any student will fully articulate the disciplinary core ideas associated with the model or use the crosscutting concepts in context in a nuanced way; however, note the ideas that are (or are not) mentioned in students' models and ensure that you do not gloss over the parts of future lessons that build or build on these ideas. For example, if no students mention electric fields in their models, ensure that in Lesson 4 students have sufficient opportunity to engage in the built-in reflections on *Electrostatics Unit*.
	Driving Question Board	The Driving Question Board is another opportunity for pre-assessment. This Driving Question Board build provides students two opportunities to generate questions before sharing with the class. The first opportunity, occurring shortly after development of a class initial consensus model, is intended to elicit more questions that can be answered with science ideas, and the second opportunity occurs after some initial engineering thinking, with the intent of helping students focus on the engineering problem in their questions. It is okay if "science" and "engineering" questions do not fall neatly into the correct rounds; the goal is instead to elicit both these types of questions. Reinforce students to generate open-ended questions, such as "how" and "why" questions and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway. If students do not use exact disciplinary core idea language in their questions, that is fine, but it provides information about how deeply students are thinking about the key science ideas in the unit and which ideas might take more time to build.
	Exit ticket	This lesson includes a social-emotional check-in as students complete an exit ticket to reflect on how they feel about exploring additional solutions to global problems related to climate change. Use this information to identify additional social-emotional supports that might be needed throughout the unit. For ideas, see the discussion of climate anxiety in the unit overview materials.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 3	Driving Question Board	**Formative** Although this is not a three-dimensional assessment moment, it is important to support coherence. This moment is intended for students to add more specific questions to the Driving Question Board now that they have a better idea how engines that use gasoline or diesel (or similar fuels to each) work. These questions should be more specific than those in the anchor lesson and include questions around why energy transfer is required to burn gasoline or diesel and why people use these fuels when they release so much carbon dioxide. To support navigation, leverage any questions students ask to motivate a more careful focus on what is happening in that reaction beyond the energy input students figured out in this lesson.
Lesson 4	*Energy & Forces* *Energy & Forces Key*	**Formative** In Lesson 4, students articulate differences in matter, energy, and forces in two different situations involving the magnetic marble and ruler model: when the "bond" between two marbles is broken, and when this "bond" is not broken. Students will be asked to explicitly tie investigation data to a working explanation or model in Lessons 10 and 11 and will continue to use the same DCI and CCC elements in subsequent lessons, so if students do not draw on their investigations as they show matter and energy changes, it is important to work as a class to come to consensus, running the investigation repeatedly as necessary. To support students in tying the marbles to actual collisions between atoms, continue referring back to the "Mapping to the Cylinder System" poster.
	Mapping Between Models *Mapping Between Models Key*	**Formative** Although the mechanistic representation in *Energy & Forces* helps show what is happening in a reaction, it is not necessarily the most useful representation to show energy transfers. In this task, students map between one of their results and a similar situation from *Electrostatics Unit*. This is an opportunity to elicit students' current understanding of energy transfer out of fields. Use that older simulation as necessary to support students in re-building understandings of fields. It is key that by the end of the consensus discussion, students are clear that energy is transferred into the field, which allows bonds to break, as they build on this idea in Lesson 5. Students have an opportunity here to revise their own models throughout the consensus discussion; collect *Mapping Between Models* after the discussion and look for places where students revised their thinking.
	Exit ticket	**Formative and Self Assessment** Students complete an exit ticket in which they leverage their investigation data to explain, in full, how data from their investigations applies to the cylinder system (rather than abstract atoms). For students that do not show proficiency in all three dimensions, provide feedback on prompts 1 and 2 that directs students to reflect on particular observations or particular portions of *Mapping Between Models*. If many students do not show evidence of using all three dimensions at grade level, you may wish to create an "ideal" response from several students' work and give students an opportunity to self assess by comparing that work to their own. The third prompt is intended to help navigate into Lesson 5, and the fourth prompt is a reflective prompt which should indicate any disconnects' between students confidence and their performance.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 5	*Predicting Energy Changes* *Predicting Energy Changes Key*	**Formative and Peer Assessment** Students once again develop "comic strip" collision models as in Lesson 4 and reflect on moving between different models in the context of forming bonds. An additional focus in this lesson, which will return in Lesson 7, is applying models to link evidence to claims. There is an opportunity here for both teacher and peer feedback. Ensure that students focus on giving useful, constructive criticism, while you focus on supporting students in the three dimensions. The disciplinary core ideas and crosscutting concept pieces in this lesson, in particular, will continue to be built throughout Lesson Set 1, so this is an opportunity to give some specific feedback in addition and prior to the electronic exit ticket **Summative and Community Building** The first Electronic Exit Ticket allows relatively quick individual assessment of students on a key LLPE. Teachers can quickly check students' understanding of matter flows and energy transfers in and out of fields. Students also have an opportunity here to reflect on their growing understanding of fuels, how they used science and engineering practices and crosscutting concepts in sensemaking, and the value of their classmates in supporting their learning. Provide feedback to support students in the practice of developing and using models, and be ready to provide classwide support and review if many students do not successfully use energy flows in and out of electric fields in their responses.
	Lesson 5 Exit Ticket (Electronic Exit Ticket) *L5 Electronic Exit Ticket*	
Lesson 6	*Modeling Energy Changes* *Modeling Energy Key*	**Formative** Students seek to model energy changes when bonds both break and form. Because of the many interactions occurring, students annotate a provided screenshot of the simulation instead of developing models from scratch. Students use this model to make arguments about energy conservation and track energy flows between particles and the electric fields between particles. Feedback may be focused on students' arguments, as this same element returns in Lesson 13, as well as their thinking around energy, matter, and fields.
Lesson 7	*Fuel Energy Released* *Fuel Energy Released Key*	**Formative** After starting the calculations as a class, students work with a partner to determine the net energy transfer out of the reaction system in combustion of gasoline and diesel. This is an opportunity for students to practice bond energy calculations, which are outside the bounds of the NGSS but useful in explaining differences between gasoline and diesel in terms of energy output. Focus on the extent to which students understand the idea of net energy transfer rather than the accuracy of students' arithmetic.
	Driving Question Board	**Self-Assessment** To navigate out of the lesson, students identify what questions they have made progress on. This is an informal opportunity for students to reflect on the class' progress. It can serve as meaningful practice for the more formal reflection which occurs in the next lesson.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 8	Class Consensus Model	**Formative** After the class brainstorms components, interactions, and mechanisms, students develop individual models which are combined into a class consensus model. This model incorporates all the key science disciplinary core ideas from Lesson Set 1 and makes use of ideas about energy and matter, with a particular focus on the energy transfers that occur when bonds break and form. Refer back to investigations throughout the class to help ensure students collectively take into account all the key ideas--energy transfer into the system to start the reaction, bonds breaking and forming in the reaction, energy transfer into and out of the fields between atoms, and quantification of the net energy output. This will be the last opportunity in the unit to solidify these ideas in the context of combustion reactions, besides the assessment that students take at the end of the lesson.
	Calculating Carbon Emissions *Calculating Carbon Emissions Key*	**Formative** After students have summarized all the key ideas about energy from Lesson Set 1 in the consensus model and apply it to explain the differences between fuels, they return to carbon emissions as a key difference between fuels. They analyze data around different fuels' properties and vehicle fuel efficiency, using unit conversions and stoichiometry as a mathematical model, to support claims about the impact of carbon-based fuel use. Drawing on ideas from *Polar Ice Unit* and *Oysters Unit*, students do calculations--however, provide as much mathematical support as necessary and allow students to focus on the impact of the data in front of them on human populations. Students should recognize that it is not sustainable for all people to use vehicles and fuels that release so much carbon dioxide and other pollutants.
	Driving Question Board	**Formative** This Driving Question Board check-in acts as a review opportunity in that students answer questions that they agree have been answered in Lesson Set 1. They also have an opportunity to add new questions to the Driving Question Board, particularly in light of the initial turn toward engineering on day 2 of this lesson. If students do not ask many engineering-focused questions, ask them to discuss again what fuels they think vehicles should use. Students should recognize that they have not looked at several fuels yet or systematically thought about which fuel is best, which will help motivate subsequent lessons. The Teacher Edition also provides guidance on using this check-in as a self-assessment opportunity.
	Cold Pack Scenario *Cold Pack Assessment* *Cold Pack Key/Rubric* *Hot Pack Scenario* *Hot Pack Assessment* *Hot Pack Key/Rubric*	**Summative** Two different phenomena are provided for the mid-unit transfer task: cold packs and hot packs. These tasks may be deployed in different ways: as alternate versions of the mid-unit task, as an initial assessment and reassessment, or as a pre- and post-test. In any version, students will draw on modeling, with an energy and matter lens, to explain endothermic or exothermic dissolution in cold or hot packs. This represents a moderate degree of transfer from the unit, in which students have only focused on exothermic, and to a lesser extent endothermic, reactions. Provide detailed feedback using the rubrics provided. Students will need ideas of energy transfer to and from fields in Lessons 9 and 11, so use those lessons as key moments to reinforce ideas from this assessment.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 9	*Discussion Mapping Tool* *Battery Design Key*	**Formative and Community Building** Students engage in a Scientists Circle discussion around arguments for and against electric vehicles. This is an important assessment opportunity for students' evaluation of arguments, as well as their thinking around how the transportation system could be changed to cause desired effects. In addition, as students move more toward engineering thinking it is important to ensure they are engaging in productive, equitable discussions. If students struggle in this discussion, it may be valuable to have them practice giving and receiving structured peer feedback on this lesson's exit ticket, to promote both reasoned evaluation of arguments and classroom community. **Formative** On day 2, students propose a design solution about which electrolyte solution and combination of electrodes should produce the highest energy output rate for the battery. This provides an opportunity for students to use M-E-F thinking and evidence from the lesson to develop a cause-and-effect mechanism that supports their argument, as described in *Battery Design Key*. The design focus assessed here will return as students build a portfolio in Lesson Set 3. Provide detailed feedback before Lesson 12 (if used) or Lesson 13.
Lesson 11	Lesson 11 Exit Ticket (Electronic Exit Ticket) *L11 Electronic Exit Ticket*	**Summative and Community Building** This second and final Electronic Exit ticket focuses on explaining energy transfer in nuclear fission. It also provides an opportunity for students to reflect on whether nuclear fission is a "good solution" and individually consider why uranium is not used in everyday vehicles for fuel, leading into the engineering focus of Lesson Set 3. Finally, students again celebrate a classmate who has helped their thinking. The thinking in this electronic exit ticket is intended to help students shift from scientific thinking, which is the primary focus of Lesson Set 1 and much of Lesson Set 2, into engineering thinking that is emphasized in Lesson 12 and Lesson Set 3. Although none of the specific elements in this task will return explicitly in the rest of the unit, provide feedback to help students tie science understandings to engineering implications.
Lesson 12	*Rocket Fuel Argument* *Rocket Fuel Argument Key*	**Pre-Assessment OR Formative OR Summative** This lesson is centered around and builds toward an assessment task in which students apply understandings of nuclear fission from Lesson 11 to a novel transportation problem--travel to space. They evaluate arguments for hydrogen-based rocket fuel to fission-based rockets, taking criteria and constraints into account and particularly considering the need to design all transportation systems in a way that minimizes pollution. This optional lesson and assessment can be deployed in multiple ways. The default is to use in place as either a formative or summative task that primarily assesses students' argumentation and thinking about designing systems to meet intended outcomes (initially built in *Oysters Unit* and returned to throughout this unit), but it could also be considered as a pre-assessment for students' engineering thinking leading into Lesson Set 3. Alternatively, it could be used at the end of the unit as a pure summative assessment, to supplement the in-unit design task.
Lessons 13-15	*STAMP Assessment Guidance* *STAMP Protocol Matrix*	**Formative** Portfolio grading is a commonly accepted way to provide feedback on student work, although it is less common in science than other disciplines like Language Arts. In the portfolio, students are given opportunities to practice with different, related sets of LLPEs, and they receive feedback from their teacher on their performance via a stamp. Then students have a chance to show revised thinking and receive a summative grade at the end of the lesson set. The STAMP Protocol is intended to help teachers provide students with immediate, in-the-moment feedback on artifacts that form a coherent record of students' engineering thinking. *STAMP Protocol Matrix* catalogs the moments in which the STAMP Protocol is used.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 13	STAMP Protocol moments	**Formative** There are three STAMP Protocol moments in Lesson 13. The first is at the beginning of day 2, when students are working on their first analysis using the consensus decision matrix (material: CE.L13.HO2]. Here, students should both consider the differential impacts of making different changes and consider the benefits and costs of each. This may be challenging, which helps motivate the development of subcategories. The second STAMP moment is later on day 2, when students are reconsidering the same proposed transportation solutions as they develop written arguments for specific subcategories. An additional STAMP moment occurs at the end of day 2, when students share their oral arguments for specific subcategories and the class comes to agreement. All three of these moments require students to leverage engineering disciplinary core ideas along with the cause and effect idea of differential effects. If you notice many students or groups are not leveraging these ideas in their thinking, you may wish to pause the class so you can provide general feedback or so students can compare work.
Lesson 14	*Transportation Arguments Draft*	**Formative, Peer, and Self Assessment** There are two STAMP Protocol moments in Lesson 14. The first moment is on day 2, students start to evaluate options via the radar charts. In doing so, they are analyzing data to support design decisions. Students then complete individual cost-benefit analyses, which includes an option for self-assessment. On day 3, students have an opportunity to develop and share arguments for the design decisions they make with peers and receive feedback, providing an opportunity for peer assessment. Later on day 3, students revise their arguments and reflect on their interactions with peers, giving students a chance to engage in self assessment along with three-dimensional learning. Teachers may provide feedback on this last assessment moment using the STAMP protocol.. Throughout, students must consider criteria, constraints, and trade-offs, and use patterns in data from radar charts to support their arguments.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 15	*Final Design Proposal* *Final Design Key*	**Summative** This final design proposal represents a culmination of student thinking in the lesson and the unit as a whole. Although this proposal is a STAMP Protocol moment, *Final Design Key* provides guidance on using it as a more formal end-of-unit assessment as well. In this task, students have the opportunity to make an argument for which fuel they think would be the best to design our next generation vehicles to use. In doing so, they quantify how it meets considerations, articulate potential benefits, risks, and costs, and explain how the fuel actually works using understanding built in Lesson Sets 1-2. The NGSS disciplinary core ideas that students will bring to this assessment include: • ESS3.A.2 Natural Resources: All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2) • ETS1.A.1 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. (HS-ETS1-1) • ETS1.A.2 Defining and Delimiting Engineering Problems: Humanity faces major global challenges today, such as the need ~~for supplies of clean water and food or~~ for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) This assessment requires students to primarily leverage this practice: • Constructing Explanations and Designing Solutions: Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. Students will leverage two key crosscutting concepts to complete this assessment: • Cause and Effect: Systems can be designed to cause a desired effect. • Energy and Matter: Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. The scoring on this assessment represents our recommendation for how to weigh the evidence provided by students in each question. Please use scoring and feedback processes that work for your class, and your requirements. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments.
	Driving Question Board	**Formative** The final Driving Question Board check-in allows students to celebrate everything they have figured out in the unit. Students can also identify questions that were not answered in this unit, which might be addressed in later courses or can serve as areas of independent research.
	Transportation Proposal Reflection	**Self Assessment** In this opportunity, as part of end-of-unit and end-of-course reflection, students have the opportunity to share the learning from the unit that they are most proud of. This is an important moment for both content and social-emotional learning, as it requires students to reflect back on their work and decide which piece was most important, meaningful, or worth holding onto for them, and reflect on *how* they figured it out. Use this feedback to both celebrate students and reflect on which pieces of the unit are most impactful, so you can raise them up in the future.

When	Assessment and Scoring Guidance	Purpose of Assessment
Embedded in each lesson	Lesson Performance Expectation Assessment Guidance	**Formative Assessment** Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in several lessons	Progress Trackers	**Formative and Student Self-Assessment** The Progress Trackers are thinking tools designed to help students keep track of how the science ideas they figure out in class influence their thinking about the unit's anchoring engineering problem of what our transportation system can and should look like. In addition to including space for students to add new criteria and constraints for evaluating fuels and transportation decisions throughout the unit, they help students connect science disciplinary core ideas and crosscutting concepts (embedded in "What we figured out") with engineering practice, in a coherent way that brings them back to ideas from the anchor. It is important that what the students write in theProgress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Trackers are meant to be a thinking tool for kids, we strongly suggest it is not collected for a summative "grade" other than for completion. Students add to their Progress Trackers in Lessons 2, 5, 7, 8, 9, 10, and 11, and use them as a tool to help them in engineering work in Lessons 10, 12 and 13.
Occurs in several lessons	Student Self-Assessment Rubrics	**Self-Assessment** Student self-assessment rubrics for giving and receiving feedback can be used throughout the unit. Opportunities include, after a discussion or at the end of a class period. The rubric helps students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how the whole-class and small-group discussions can be more productive. Additional support can be found in the *OpenSciEd Teacher Handbook: High School Science.* In addition to the self-assessment moments described above, this tool's use is suggested as an alternate activity in Lessons 5 and 7.
Occurs in several lessons	Routines and Tools to Support Peer Assessment	**Peer Assessment** There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback. We suggest that peer feedback happen at least two times per unit. Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good opportunities to use a peer feedback protocol. They do not need to be final pieces of student work; rather, peer feedback will be more valuable to students if they have time to revise after receiving it. This should be a formative rather than summative type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities in which they can use these experiences as evidence for the feedback they give. Additional support can be found in the *OpenSciEd Teacher Handbook: High School Science.* Use of one or more of these tools is explicitly suggested for peer assessment moments in Lessons 5 and 14.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Develop a model based on evidence (chemical formula, energy released, and carbon dioxide emission) to illustrate the matter change, energy transfer, and force interaction relationships between the components of the system to explain how a fuel (matter) is used to provide energy in a vehicle system to make it move. (SEP: 2.3; DCI: PS3.A.2, PS3.A.4; CCC: 5.3) **1.B** Ask questions that arise from and seek additional information about: patterns in data related to fuel use in transportation; attempts to explain how matter (fuel) and energy transfer in a vehicle to produce movement; and attempts to identify criteria and constraints to inform design solutions for next-generation vehicle fuel use. (SEP: 1.1, 1.8; DCI: PS3.A.2, ESS3.C.2; CCC: 5.2)	**1.A When to check for understanding:** 1. As students individually develop their initial models on *Initial Fuel Model* on day 1. (**slide J**) 2. As students compare initial models with a partner on day 2. (**slide N**) 3. As students work to develop an initial class consensus model on day 2. (**slides O-R**) **What to look/listen for across opportunities 1-3:** • Students identify components of the vehicle system, such as fuel or battery, engine, and exhaust/air. (SEP: 2.3) • Students draw on evidence and previous science understandings to show how vehicle components interact. (SEP: 2.3) • Students trace energy as it moves between different components of the vehicle system. (DCI: PS3.A.2; CCC: 5.3) • Students identify locations of forces (fields) within the vehicle system. (DCI: PS3.A.4; CCC: 5.3) • Students consider how changes in matter result in changes in energy and forces. (DCI: PS3.A.2) • See *Initial Model Ideas* for guidance. **1.B When to check for understanding:** 1. On day 2, as students write questions about scientific principles related to the phenomenon. (**slide S**) 2. As students write questions about engineering design considerations related to the phenomenon. (**slides T-V**) **What to look/listen for across opportunities 1-2:** • Students ask questions related to fuels, emissions, energy released, or climate change. (SEP: 1.1; DCI: PS3.A.2, ESS3.C.2) • Students ask questions about changes in matter, energy transfer, or forces that relate to what happens inside an engine. (SEP: 1.1; CCC: 5.2) • Students identify criteria and constraints and ask questions about the benefits or trade-offs of different fuels. (SEP: 1.8; DCI: ESS3.C.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	**2.A** Construct and revise an explanation based on models showing the structure and function of vehicle components that explains how chemical processes release energy, allowing the vehicle to move. (SEP: 6.2; DCI: PS1.B.1; CCC: 6.1) **2.B** Develop, revise, and use models based on evidence to identify relationships between changes in matter and energy transfers that take place in a vehicle as a result of the combustion of fuel. (SEP: 2.3; DCI: PS1.B.1; CCC: 5.2) **2.C** Analyze data using CODAP to identify patterns in carbon-based fuel characteristics that optimize the successful movement of a vehicle when burned in an internal combustion engine. (SEP 4.6; DCI: PS1.B.1; CCC 1.3)	**2.A When to check for understanding:** 1. As students discuss a possible mechanism to account for vehicle movement and identify gaps in their explanations. (**slides D-E**) 2. On day 1, when students revise their explanations of the mechanism to explain vehicle movement. (**slide I**) **What to look/listen for across opportunities 1-2:** • Students share explanations based on evidence that identify the connections between various components of a vehicle to explain how they work together to make the vehicle move. (SEP: 6.2; CCC: 6.1) • Students state that the energy released from burning fuel causes the piston to move, which ultimately causes the wheels to move. (DCI: PS1.B.1; CCC: 6.1) **2.B When to check for understanding:** 1. On day 1, when students apply M-E-F thinking to revise their initial models from Lesson 1. (**slide J**) 2. On day 2, as students balance the third chemical equation on *Balancing Fuel Equations* in small groups. (**slide W**) 3. As the class co-develops the "M-E-F Model of the Engine Cylinder" on day 2. (**slides Y-Z**) 4. On day 3, as students complete *Revised Gasoline Model*. (**slide CC**) **What to look/listen for across opportunities 1-4:** • Students develop and revise models to incorporate evidence from models and investigations to track and identify changes in matter and energy transfers. (SEP: 2.3; CCC: 5.2) • Students develop a model to track matter flows in combustion reactions by balancing chemical equations. (SEP: 2.3; CCC: 5.2) • Students determine that combustion reactions result in the rearrangements of reactant molecules into two possible products. (DCI: PS1.B.1) • Students suggest that energy is released during combustion reactions to explain changes in the speed of product particles. (DCI: PS1.B.1) • Students identify that increased forces as a result of changes in particle speed due to a chemical reaction transfer energy, causing objects to move. (DCI: PS1.B.1; CCC: 5.2) **2.C When to check for understanding:** On day 3, when students have analyzed data in CODAP using *Fuel Data Comparisons*. (**slide FF**) **What to look/listen for in the moment:** • Students analyze a CODAP data set to identify patterns of energy, efficiency, and carbon emission for various fuels. (SEP: 4.6; CCC: 1.3) • Students determine that diesel and biodiesel provide more energy than gasoline. (DCI: PS1.B.1) • Students suggest that due to diesel's energy content and abundant usage, it could serve as an optimal alternative to gasoline. (SEP: 4.6; DCI: PS1.B.1)
Lesson 3	**3.A** Evaluate the impact of the relationship between pressure, volume, and temperature of air (data) on the working model of a diesel engine by identifying energy transfer from the motion of the piston to the air particles in the cylinder as the cause of the temperature increase (effect). (SEP: 4.5; DCI: PS3.A.2, PS3.B.2; CCC: 2.2)	**3.A When to check for understanding:** 1. When students explore pressure, volume, and temperature data in CODAP using *Air Property Data*. (**slide H**) 2. When the class leverages M-E-F thinking to identify the moving piston as the source of the energy that increases the air temperature during compression. (**slide S**) **What to look/listen for across opportunities 1-2:** • Students evaluate pressure, volume, and temperature data to identify qualitative relationships between these properties. (SEP: 4.5; CCC: 2.2) • Students identify energy transfer from the motion of the piston to the air particles in the cylinder as the mechanistic cause of the temperature increase (effect) at the particle level. (DCI: PS3.A.2, PS3.B.2; CCC: 2.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	**4.A** Evaluate the impact of new data on the model of the cylinder system to conclude that changes in matter and energy occur when a bond is broken. (SEP: 4.5; DCI: PS1.B.1; CCC: 5.2) **4.B** Develop and revise models based on evidence to illustrate the energy transfers between components of a system to explain why a minimum amount of energy input is required to break bonds of stable reactant molecules in combustion reactions. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1, PS3.C.1; CCC: 5.2)	**4.A When to check for understanding:** 1. During a whole-class discussion of groups' investigation results. (**slide K**) 2. As students complete an exit ticket. (**slide AA**) **What to look/listen for across opportunities 1-3:** • Students use investigation data to describe where energy transfers and matter changes occur in the system. (SEP: 4.5; CCC: 5.2) • Students identify that collisions between particles can lead to rearrangements of atoms, or the breaking of bonds. (DCI: PS1.B.1) • Students tie rearrangements of atoms, or the breaking of bonds, to energy stored in the field. (DCI: PS1.B.1) • Students tie their new data back to energy flows in the cylinder system. (SEP: 4.5; CCC: 5.2) **4.B When to check for understanding:** 1. As students use data to develop models on *Energy & Forces*. (**slides L-N**) 2. As students revise the "As opposite charges move..." model from *Electrostatics Unit* and apply it to their energy transfer models. (**slides W-Z**) **What to look/listen for across opportunities 1-2:** • Students' models include changes (speed and position) in the particles (matter) at different points of time in the system. (SEP: 2.3; CCC: 5.2) • Students' models include changes in energy (kinetic energy of particles and/or energy stored in the field) at different points of time in the system. (SEP: 2.3; DCI: PS1.B.1) • Students' models show revisions that reflect evidence gathered from the simulation. (SEP: 2.3) • Students identify a minimum amount of energy transferred into the system for breaking the bonds of reactant molecules. (DCI: PS1.A.4; CCC: 5.2) • Students identify that when one particle interacting through a field changes its relative position to another particle it is attracted to, the energy stored in the field changes. (DCI: PS3.C.1; CCC: 5.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 5	**5.A** Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, 6.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.2) **5.B** Evaluate claims about fuels and trace the conservation of energy from the fuel's formation to its use while considering the impacts fuels and their use have had on human populations. (SEP: 7.2; DCI: ESS3.A.1, ESS3.B.1; CCC: 5.3)	**5.A When to check for understanding:** 1. During the whole-class discussion about the Marble Interactions Demonstration data. (**slide E**) 2. When students make their predictive models of energy change during bond formation on *Predicting Energy Changes*. (**slide H**) 3. During the whole-class discussion about relationships between matter, energy, and forces after using the simulation. (**slide J**) 4. As students complete the reflection on *Predicting Energy Changes*. (**slide L**) 5. As students assess the claim about energy transfers on *Predicting Energy Changes*. (**slide M**) 6. As students complete the Electronic Exit Ticket. (**slide T**) **What to look/listen for across opportunities 1-6:** • Students identify evidence of energy transfers by sharing observations about the changes in kinetic energy. (DCI: PS1.B.1; CCC: 5.2) • Students develop and use models and identify changes in matter and energy and energy transfers. (SEP: 2.4; CCC: 5.2) • Students identify the relationship between objects moving through a field and changes in energy. (DCI: PS3.C.1) • Students identify areas of agreement and disagreement in their models. (SEP: 2.4) • Students identify both the merits and limitations of the simulation and the magnet marble and ruler system. (SEP: 2.4) • Students cite their models in their assessment of the claim. (SEP: 6.4) • Students confirm the claim that energy flows from fields to particles when a bond forms. (DCI: PS1.B.1, CCC: 5.2) **5.B When to check for understanding:** During the debrief discussion after students read about fossil fuels and biofuels. (**slide R**) **What to look/listen for across the opportunity:** • Students connect both fuels back to the sun as the original energy source. (CCC: 5.3) • Students discuss the claims in the article as to impacts of the two fuels on human populations while considering the continued use of both fuels. (SEP: 7.2; DCI: ESS3.A.1, ESS3.B.1)
Lesson 6	**6.A** Develop and revise models based on evidence and use these to present and compare an argument for an explanation of where energy is transferred to and from and why energy is conserved within a system when bonds break and form. (SEP: 2.3, 7.4; DCI: PS1.B.1, PS3.C.1; CCC: 5.1, 5.2)	**6.A When to check for understanding:** 1. As students discuss simulation results. (**slides I-J**) 2. As students work in pairs to complete *Modeling Energy Changes*. (**slide L**) **What to look/listen for across opportunities 1-2:** • Students connect relative energy transfer when bonds are broken and formed to bond strength. (DCI: PS1.B.1; CCC: 5.2) • Students identify transfers of energy between particle motion and fields between particles when bonds are broken and formed. (DCI: PS1.B.1; CCC: 5.2) • Students use evidence from the computational model to support their ideas. (SEP: 2.3; DCI: PS1.B.1, PS3.C.1; CCC: 5.1, 5.2) • Students annotate their models to show the points in time when the kinetic energy of particles decreases and total energy stored in the field(s) increases. (SEP: 2.3; CCC: 5.2) • Students annotate their models to show the points in time when the kinetic energy of particles increases and total energy stored in the field(s) decreases. (SEP: 2.3; CCC: 5.2) • Students annotate their models to show that as particles change position, the energy stored in the field changes. (SEP: 2.3; DCI: PS3.C.1) • Students argue that the total energy in the system does not change. (SEP: 7.4; CCC: 5.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 7	**7.A** Respectfully provide critiques based on scientific arguments to determine that the cause of varying energy transfer from reactions is due to differences in energy stored in the fields between bonded atoms. (SEP: 7.3; DCI: PS3.C.1; CCC: 2.2) **7.B** Apply scientific reasoning and models to claims to consider the relative scale of energy transfer into and out of fields in a closed system as the atoms in molecules change relative position. (SEP: 6.4; DCI: PS3.B.3; CCC: 3.1, 5.1)	**7.A When to check for understanding:** 1. As students discuss the implications of both breaking and forming bonds. (**slides B-C**) 2. As students discuss the investigation results. (**slides I-K**) **What to look/listen for across opportunities 1-2:** • Students suggest cause-and-effect relationships that rely on smaller-scale mechanisms. (CCC: 2.2) • Students argue that the transfer of energy is the result of relative bond strengths and the consequent energy stored in the fields of the reactant and product bonds. (SEP: 7.3; DCI: PS3.C.1) • Students use reasoning and evidence to respectfully construct critiques for a hypothetical student's response about which differences in bond strengths would result in energy being transferred out of the field through smaller-scale mechanisms. (SEP: 7.3; CCC: 2.2) • Students' critiques guide the hypothetical student's thinking to conclude that more energy must be transferred into the field to break a strong bond and transferred out of the field when a strong bond is formed. (SEP: 7.3; DCI: PS3.C.1) **7.B When to check for understanding:** 1. As students discuss the variation in the predicted and experimental energy differences. (**slides P-Q**) 2. As students consider the ideal fuel for powering a semi truck. (**slides R-S**) **What to look/listen for across opportunities 1-2:** • Students' claims use bond energies and atoms' changing relative positions as evidence to describe and predict energy changes in the system. (SEP: 6.4; DCI: PS3.B.3) • Students consider the boundaries for the energy transfer out of fields within the closed engine system. (DCI: PS3.B.3; CCC: 5.1) • Students recognize that the amount of energy provided to the vehicle depends on the relative scale of fuel burned as atoms rearrange. (DCI: PS3.B.3; CCC: 3.1)
Lesson 8	**8.A** Develop a model based on evidence to illustrate energy transfer into or out of a chemical reaction system depending on energy transfer into and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2) **8.B** Use mathematical models to show that matter is conserved during fuel combustion and to support claims about fuel efficiency in vehicles and the impacts of carbon-based fuel use. (SEP: 4.1; DCI: ESS3.B.1; CCC: 5.1)	**8.A When to check for understanding:** 1. On day 1 as students develop a Gotta-Have-It Checklist. (**slides C-E**) 2. On day 1 when students model in pairs. (**slide F**) 3. As students complete *Cold Pack Assessment* or *Hot Pack Assessment*. (**slide Z**) **What to look/listen for across opportunities 1-3:** • Students use evidence to propose possible components and relationships that should be included in a model. (SEP: 2.3) • Students include changes in kinetic energy by identifying energy flows within, into, and out of electric fields and a defined system. (DCI: PS1.B.1; CCC: 5.2) • Students represent electric fields, stable molecules, separated atoms, and changes in kinetic energy. (DCI: PS1.A.4) **8.B When to check for understanding:** 1. On day 2 as students determine carbon emissions for a chosen fuel on *Calculating Carbon Emissions*. (**slide M**) 2. On day 2 when the class debriefs their calculations. (**slide N**) **What to look/listen for across opportunities 1-2:** • Students use mole ratios from the balanced chemical equation to help them determine the carbon dioxide produced by the combustion of fuel. (SEP: 4.1; CCC: 5.1) • Students cite calculations as evidence that some fuels release more CO_2 than others. (SEP: 4.1; CCC: 5.1) • Students relate the use of carbon-based fuels to climate change as an impact on human populations. (DCI: ESS3.B.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 9	**9.A** Compare and evaluate arguments about a new transportation technology (batteries and EVs) to reduce pollution while considering its impact on the transportation system. (SEP: 7.1; DCI: ESS3.C.2; CCC: 2.3) **9.B** Use evidence from student investigations and research to propose a battery design that results in the largest energy output based on the types of solutions and metals used in the battery and the matter and force interactions between them. (SEP: 6.5; DCI: PS3.A.4; CCC: 2.2)	**9.A When to check for understanding:** 1. As students engage with each other as they synthesize evidence from the arguments for and against electric vehicles. (**slides D-F**) 2. As students update their Progress Trackers on day 2. (**slide FF**) **What to look/listen for across opportunities 1-2:** • Students compare and evaluate arguments for and against electric vehicles using currently accepted explanations (burning fossil fuels releases CO_2), new evidence (life cycle thinking), limitations and constraints (accessibility), and ethical issues (concerns about mining). (SEP: 7.1; DCI: ESS3.C.2) • Students identify that batteries and EVs can be used to reduce pollution but still have an environmental impact, and that these concerns could be partly addressed by improving batteries. (DCI: ESS3.C.2; CCC: 2.3) • Students consider explanations of how batteries work as they evaluate electric vehicles as a design solution. (SEP: 7.1) **9.B When to check for understanding:** As students develop their battery design proposals on day 2. (**slide EE**) **What to look/listen for across the opportunity:** • Students explain that a battery transfers electrons between two different substances through a wire to generate an electric current. (DCI: PS3.A.4, CCC: 2.2) • Students explain that electrolytes in the battery break into ions which move through water to generate an electric current (energy). (DCI: PS3.A.4; CCC: 2.2) • Students identify specific pieces of investigation data and evidence from *Electrolyte Current Data* to support their proposed battery design. (SEP: 6.5) • Students explain that their design has a higher ion concentration and therefore greater energy output. (DCI: PS3.A.4; CCC: 2.2) • Students explain that the chosen metal combinations contain one metal that is better at releasing their electrons and one metal that is better at gaining electrons, which results in greater energy output. (DCI: PS3.A.4; CCC: 2.2)
Lesson 10	**10.A** Analyze data about greenhouse gasses from hydrogen production and evaluate their impact on the transportation system to optimize it relative to criteria of greenhouse gas emissions to preclude ecosystem degradation. (SEP: 4.5, 4.6; DCI: ETS1.A.1, ESS3.C.2; CCC: 2.3)	**10.A When to check for understanding:** 1. As the class discusses hydrogen production (**slide G**). 2. As partners work together to update their Progress Trackers (**slide T**). **What to look/listen for across opportunities 1-2:** • Students analyze the data on **slide G** to identify hydrogen production from fossil fuels as a source of carbon dioxide emissions (a greenhouse gas) in conflict with our criterion of lowest carbon dioxide emissions possible. (SEP: 4.5; DCI: ESS3.C.2, ETS1.A.1) • Students analyze the data on **slide G** to identify hydrogen production from water as a source of oxygen emissions, which satisfies our criterion of low emissions from other pollutants. (SEP: 4.5; DCI: ESS3.C.2, ETS1.A.1) • Students cite carbon dioxide (a greenhouse gas) produced during the transformation of fossil fuels into hydrogen gas as being in conflict with the criterion of a transportation system with low carbon dioxide emissions. (DCI: ESS3.C.2, ETS1.A.1; CCC: 2.3) • Students cite methane, the main fossil fuel used to produce hydrogen, and the potential for leaks during its lifecycle as being in conflict with the criterion of a transportation system with low other pollutants. (DCI: ESS3.C.2, ETS1.A.1; CCC: 2.3) • Students include engineering implications that cite the need to lower the greenhouse gas emissions associated with hydrogen production for a viable next generation transportation system using hydrogen as a fuel. (DCI: ESS3.C.2, ETS1.A.1; CCC: 2.3) • Students tie data about fueling options to criteria and constraints on a transportation system. (SEP: 4.6)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	**11.A** Construct an explanation based on a variety of sources using structure-function relationships to show how protons and neutrons are conserved during nuclear fission while energy is released. (SEP: 6.2; DCI: PS1.C.1; CCC: 6.1, 5.5) **11.B** Evaluate the impact of new data related to nucleus structures on the model of energy transfer in and out of fields during nuclear fission. (SEP: 4.5; DCI: PS3.C.1, PS1.C.1; CCC: 6.1) **11.C** Apply scientific ideas, principles, and evidence to identify unanticipated effects of a transportation design solution that may result in problems in the system due to associated costs and risks. (SEP: 6.3; DCI: ESS3.A.2; CCC: 2.3)	**11.A When to check for understanding:** 1. On day 1, as students analyze the nuclear reactor. (**slides C-D**) 2. On day 1, when students examine the matter changes in nuclear processes. (**slides F-G**) 3. On day 1, during the Building Understandings Discussion about energy. **(slides K-L)** 4. On day 3, when students complete an Electronic Exit Ticket. (**slide AA**) **What to look/listen for across opportunities 1-4:** • Students should suggest initial explanations that use evidence from the diagram to identify structures and their connections and propose possible functions of the components. (SEP: 6.2; CCC: 6.1) • Students should explain that matter is conserved because the number of protons and neutrons is constant. (SEP: 6.2; CCC: 5.5) • Students should use evidence from the nuclear "equations." (SEP: 6.2; DCI: PS1.C.1) • Students should initially explain, using evidence from the simulation, equations, and diagram, how energy is released in nuclear fission. (SEP: 6.2; DCI: PS1.C.1) • Students should articulate that the same particles rearrange in nuclear fission (matter is conserved). (CCC: 5.5) • See *L11 Electronic Exit Ticket* for guidance. **11.B When to check for understanding:** On day 2, when students map the reading to the simulation. (**slide R**) **What to look/listen for during the opportunity:** • Students should evaluate how the data from the reading affects our working explanation of how nuclear fission provides energy. (SEP: 4.5; DCI: PS3.C.1) • Students identify that nuclear fission must include a different force relationship between components than chemical processes do. (CCC: 6.1) • Students track energy transfers in and out of nuclear and electric fields, which results in massive energy transfer out of the system from electric fields. (DCI: PS3.C.1) **11.C When to check for understanding:** On day 3, as students update their Progress Trackers. (**slide Z**) **What to look/listen for during the opportunity:** • Students articulate unanticipated effects in the use of nuclear fission for transportation, including costs and risks like environmental damage, negative health effects, high initial investments, and the need for miniaturization. (SEP: 6.3; DCI: ESS3.A.2) • Students identify the problems with system design that could result if uranium was used as a fuel without addressing unanticipated effects. (DCI: ESS3.A.2; CCC: 2.3)
Lesson 12	**12.A** Compare and evaluate competing rocket fuel options for future space missions specifying qualitative and quantitative criteria and constraints that account for societal want of space exploration and environmental impact. (SEP: 7.1; DCI: ETS1.A.1, ETS1.A.2; CCC: 2.3)	**12.A When to check for understanding:** When students compare arguments for fuels. (**slide H**) **What to look/listen for during the opportunity:** • Students compare arguments for possible rocket fuels in light of new environmental impacts to generate the criteria and constraints of future space missions. (SEP: 7.1; DCI: ETS1.A.1) • Students propose a rocket fuel source or other possibilities to help minimize negative impacts (e.g., environmental) and maximize positive results. (DCI: ETS1.A.2; CCC: 2.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 13	**13.A** Compare and evaluate the potential impacts of two transportation options (current state vs. possible future state) caused by the engineering approach (shift, avoid, improve) as well as the availability and accessibility of the needed resources. (SEP: 7.1; DCI: ETS1.B.1, ESS3.A.1; CCC: 2.4) **13.B** Present an oral and written argument for the need for specific subcategories of criteria that can be approached systematically, based on data and evidence, that shows differential effects such as benefits and costs resulting from changes in the transportation system. (SEP: 7.4; DCI: ETS1.C.1, ESS3.A.2; CCC: 2.4)	**13.A When to check for understanding:** As students are creating their individual evaluations of transportation solutions using the class consensus decision matrix. (**slide J**) **What to look/listen for during the opportunity:** • Students consider the effects of implementing new transportation solutions as well as estimate the size of the effects for accessing or implementing those solutions. (DCI: ESS3.A.1; CCC: 2.4) • Students identify and compare the benefits and costs (economic, aesthetic, social, cultural, and environmental), safety, and reliability of two transportation system solutions. (SEP: 7.1; DCI: ETS1.B.1) **13.B When to check for understanding:** 1. When students work in small groups to create subcategories for one criterion or constraint. (**slides M-N**) 2. As students argue for their subcategories to be added to the consensus decision matrix. (**slide O**) **What to look/listen for across opportunities 1-2:** • Students use the idea of differential effects (benefits and costs) of transportation solutions to Earth systems. (DCI: ESS3.A.2; CCC: 2.4) • Students use data and evidence to develop written arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1) • Students use data and evidence to develop oral arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1)
Lesson 14	**14.A** Analyze data using quantitative tools to evaluate future transportation options that satisfy requirements set by society, by using numerical patterns in evidence from radar charts and cost-benefit calculations. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4) **14.B** Develop an argument for the best future transportation options that satisfy requirements set by society, by using numerical patterns in evidence and feedback from peers to refine arguments. (SEP: 6.5, 7.3; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)	**14.A When to check for understanding:** 1. As students rate their top five transportation options for energy released, financial cost, safety, environmental impact, and infrastructure as a group at the end of day 1 and beginning of day 2. (**slides J-K**) 2. As students interpret their ratings after examining the radar charts they generated. (**slides M-N**) 3. As students complete *Cost-Benefit Analysis*. **(slides S-T)** **What to look/listen for across opportunities 1-3:** • Students quantify the value of transportation solutions based on their ability to satisfy various requirements set by society. (DCI: ETS1.A.1, ESS3.A.2) • Students use mathematical representations in their quantitative tools to track patterns in their data. (SEP: 4.1; CCC: 1.4) • Students use numerical data from quantitative tools to evaluate which options are best to use in the future. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2) **14.B When to check for understanding:** 1. As students complete Part 1 of *Transportation Arguments Draft* on day 2. (**slide V**) 2. As students share their arguments with the Stand Up-Hand Up-Pair Up protocol on day 3. **(slide X)** 3. As students complete Parts 2 and 3 of *Transportation Arguments Draft* on day 3. (**slide Z**) **What to look/listen for across opportunities 1-3:** • Students support their arguments using patterns they observe from evidence. (SEP: 7.3; CCC: 1.4) • Students articulate how they prioritized the requirements set by society based on their personal values and the impacts of that prioritization on their decision. (SEP: 6.5; DCI: ETS1.A.1) • Students respectfully pose clarifying questions to respond to diverse perspectives, probe for reasoning and evidence, and challenge ideas or conclusions to evaluate the strength of peers' arguments. (SEP: 7.3) • Students revise and/or refine their arguments for the best future transportation options. (SEP: 7.3; DCI: ESS3.A.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 15	**15.A** Apply knowledge about the costs and benefits of resource extraction and energy and resource use and quantify them to propose vehicle systems or transportation goals designed to reduce carbon emissions and meet prioritized criteria and address trade-offs. (SEP: 6.5; DCI: ETS1.A.1, ETS1.A.2, ESS3.A.2; CCC: 2.3, 5.2)	**15.A When to check for understanding:** On day 1 as students write their final arguments for one design solution. (**slide B**) **What to look/listen for during the opportunity:** • Students propose a specific design solution for future transportation and discuss potential benefits and risks. (SEP: 6.5; DCI: ESS3.A.2) • Students' proposed vehicle or transportation systems are designed to help minimize environmental impacts. (DCI: ETS1.A.2; CCC: 2.3) • Students' design solutions quantify how they meet the specified considerations. (SEP: 6.5; DCI: ETS1.A.1) • Students' proposed vehicle or transportation systems leverage energy and matter flows while minimizing negative environmental impacts. (DCI: ETS1.A.2; CCC: 5.2)

Lesson-Specific Teacher Materials

Lesson 1 Teacher Reference

Supporting Student Questions

Student questions in this unit will likely center around fuel types. Thus, the unit is organized to investigate the following "groups" of questions:
1) fossil fuels and biofuels (Lesson Set 1),
2) batteries (Lesson 9),
3) hydrogen (Lesson 10),
4) uranium (Lessons 11 & 12), and
5) how to engineer a system of transportation using different combinations of these technologies (Lesson Set 3).
Although some engineering questions are answered throughout, the majority of engineering questions are answered in Lesson Set 3 as students develop a proposal for addressing emissions from transportation..

Here are some common questions high schoolers have generated in response to the anchoring phenomenon routine in Lesson 1:

Common DQB Questions Related to Lessons 2 and 3

- How does fire make the car move?
- How does the gasoline/fuel transfer into exhaust or CO_2?
- Why do cars take gasoline while trucks take diesel?
- What is the difference between vehicles running off of diesel rather than gas?
- How is regular gasoline different from diesel?
- Why doesn't diesel need a spark?
- Does diesel burn hotter?
- Is diesel more efficient?
- Does diesel work the same as gasoline?
- Can we put any fuel in our cars?
- Can we put diesel in our cars?

At the end of Lesson 3, students have an opportunity to add more questions to the Driving Question Board. These questions should be more specific and focused than those on the initial Driving Question Board and will likely be answered in Lessons 4-8:

- Why do you need energy for the reaction?
- Why do we use gas or diesel even though they release lots of CO_2?
- Where is the energy coming from when you burn gas?

Common DQB Questions Related to Lessons 4-8 (Combustion of carbon-based fuels)

- Do certain vehicles produce more CO_2 than others? If so, why?
- What is the connection between type of fuel and the amount of CO_2 released?
- Why does it need so much gas to work?
- How does the engine turn a liquid (gas) into energy?
- How does gas make the car move?
- How does gasoline work?
- How does gas make it go?
- What do different chemicals do in the engine?
- What is the most reliable fuel?
- Is ethanol better than gas?
- Where do fossil fuels come from?
- Can I put jet fuel in my car?
- Can anything be a fuel?

In Lesson 8, students will generate additional questions. These questions may ask more engineering-focused questions about carbon-based fuels, or may start to apply thinking from the first lesson set to other fuels. For example:

- What other options for fuels exist other than carbon-based fuels?
- How do we know what fuels to use that release less CO_2?
- Can we design more efficient cars that burn less fuel?
- What other transportation options exist other than driving individual cars?

Common DQB Questions Related to Lesson 9 (Batteries)

- Are batteries/electric renewable?
- How long does the battery last in electric cars?
- How long will it take for electric cars to charge?
- Do electric cars make CO_2?
- How do electric cars not give any exhaust?
- Is an electric car more expensive to design than gas?
- Is it possible for electric cars to dominate over fossil fueled cars?
- What makes gasoline cars stronger and faster than electric cars?
- Which car consumes more energy, an electric car or a gasoline car?

Common DQB Questions Related to Lesson 10 (Hydrogen)

- How does hydrogen make energy?
- Why isn't hydrogen popular?
- Where do you even get hydrogen?

Common DQB Questions Related to Lesson 11 & 12 (Uranium)

- Can uranium power a car?
- The used or discarded material from using uranium has to be stored somewhere. How/where would it all be stored and could it be stored near people?
- Could we make it safer to use uranium?
- Would uranium make car explosion rates go up due to it being in nuclear things?
- Why doesn't more equipment use uranium as fuel instead of gas or diesel?
- Would you use uranium when it's hard to find and can blow up the car?
- Does nuclear energy have long lasting harmful effects on the atmosphere?

Common DQB Questions Related to Lesson 13-15 (Engineering Design)

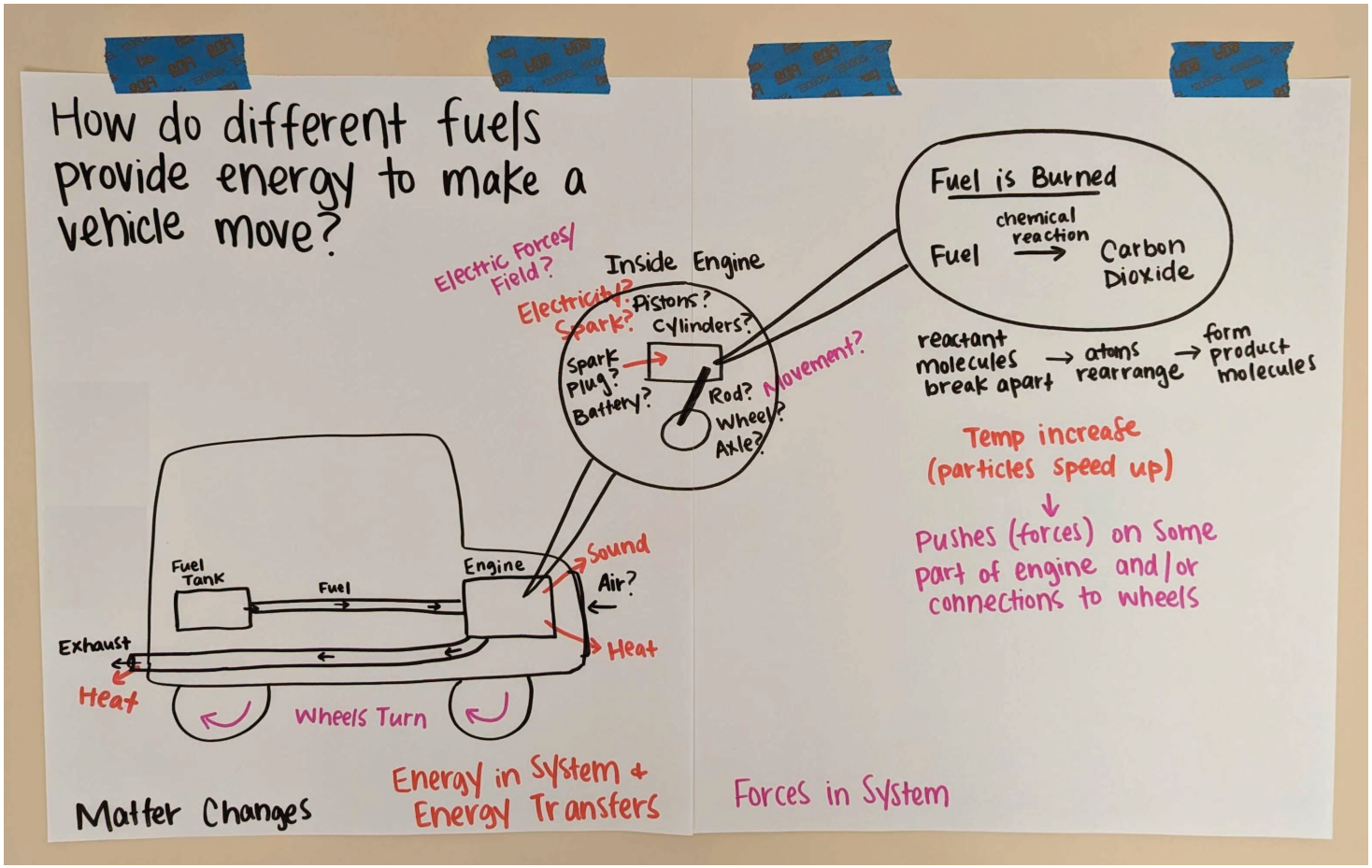
- Which fuel is the easiest to get?
- What changes do we have to make to our infrastructure to implement a new renewable fuel source?
- Can some other energy be used to move the car?
- Is there any way we can reduce carbon emissions without being primarily electric?
- Why are there so many fuel choices?
- How much is it gonna cost?
- What are the problems of using fuel in cars?

Common DQB Questions Related to Lesson 14 (Cost-Benefit Analysis)

- How much is the engine going to cost for cars and trucks?
- What type of fuel costs less but helps the environment?
- Would people really want to buy it? Is it really a thing people want?
- Is the cost going to be a lot for this project?
- Could we feasibly stop using gasoline without making cars incredibly expensive?

Lesson 1: Answer Key

Initial Model Ideas



Look/listen for these ideas:

Matter changes/transfers in parts of the vehicle system

- **Matter flow into the vehicle**
  - Fuel goes from a storage tank in the vehicle (as a gas or a liquid) to the engine, for many of the vehicles.
  - Other fuels such as batteries, hydrogen, and uranium will have more question marks about where the fuel is located in the vehicle and its state of matter (e.g., solid?).

    - Some students may mention air flow or oxygen flow into the engine.
- **Matter flow out of the vehicle**
    - Exhaust fumes, or emissions, are released for most of the fuels. These emissions will include CO_2.
    - If students modeled other fuels such as lithium, hydrogen, and uranium, they will say that the fuels emit no byproducts; however, uranium and batteries may include waste material(s) associated with disposal.
- **Particle-level changes in the matter**
    - In most of the fuels fuels, these changes likely will be described as burning or combustion:
        - This is a chemical reaction (based on students' prior work in middle school in *OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)* and *OpenSciEd Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)*).
        - This would mean that there is a breaking apart of molecules into atoms and a formation of new molecules out of those atoms.
    - If students modeled a battery, they may suggest that electrons are moving off of some material or substance in the battery.
    - If students modeled other fuels such as hydrogen or uranium, it is less likely that they will identify a particular particle-level process.

Energy changes/transfers in the engine

- Energy is somehow released in burning.
- As things heat up, the temperature or speed of particles increases.
- Energy is somehow transferred from the engine to the wheels (or another part of the vehicle that makes it move, such as a propeller).
- Collisions between particles transfer energy (e.g., conduction).
- Some students may mention that a battery provides the energy in a spark to start many combustion engines, while students who are familiar with diesel may suggest that this isn't always needed for other fuels.

Force changes/transfers in the engine It is less likely that students will take a forces perspective. If they do, these ideas may come up:

- Particles in the engine collide with and push on piston surfaces.
- Solid structures in the engine push/pull on each other through contact forces (e.g., crankshafts attached to pistons, gears, etc.).
- The forces within or between molecules or in a spark (e.g., electrostatic forces between electrons, atoms, or molecules).

Lesson 2 Teacher Reference

L2 Demonstrations Summary

General safety protocols for demonstrations and hands-on activities:
Prior to doing any of the demonstrations, read through the "safe handling of alcohol in the laboratory" and be certain to follow all safety protocols noted: https://www.nsta.org/safer-handling-alcohol-laboratory.

Noted protocols needing special attention include the following:

- Conduct a hazards analysis and risk assessment of the use of alcohol and review safety action to be taken before doing any lab investigation or demonstration. Prepare a list of the significant hazards in the procedure and identify the controls necessary to minimize them. The procedure, hazards analysis, and risk assessment should be reviewed and approved by the Chemical Hygiene Officer (or designee) as indicated by the Chemical Hygiene Plan.
- Demonstrations are to be conducted under a fume hood to capture and prevent any flammable and/or combustible concentrations of vapors from reaching any source of ignition.
- If a fume hood is not available during a demonstration, place an impact-resistant barrier between the experiment and students. Also ensure that students or other observers are more than 10 feet (~3 meters) away (NFPA 45). The safety shield should be made of impact-resistant plastic or tempered glass and be 24" high and extend 12" beyond the hazard in both directions. All individuals (adults and students) in the room should wear the appropriate safety goggles during the demonstration. In the absence of a permanent fume hood, a portable fume hood that is rated for alcohol use can be used.
- Make sure all laboratory occupants are wearing sanitized indirectly vented chemical splash goggles and non-latex aprons during the demonstration set-up, hands-on and takedown portions.
- Know the location of the A-B-C fire extinguisher, fire blanket, fire alarm, eyewash, and shower and be able to reach them within 10 seconds. Teachers should receive annual training so that they know how to use each of these items. If district policy prohibits the use of a fire extinguisher, in the event of fire, evacuate the room, close the door, and pull the fire alarm.
- Review the SDS before using alcohol and make students aware of all hazards.
- Practice the laboratory or demonstration before conducting it with students.

Demonstration	Purpose	Materials	Safety
Fire Combustion Demonstration 1 (burning ethanol in tea candle holder) Start of https://youtu.be/WsxQvzJqmzM	Gather initial evidence of matter changes and energy transfers. • The fuel burns. • We saw light from the igniter and the flame. • If we put our hands near the beaker it would feel hot.	tea candle holder (with no candle) 1000 mL glass beaker 50 mL ethanol or isopropyl alcohol Piezo igniter	In addition to the standard safety considerations, read through the safe handling of ethanol in the laboratory guidance: https://www.nsta.org/safer-handling-alcohol-laboratory. Operate the Piezo igniter only as directed.
Fire Combustion Demonstrations 2 & 3 (covering the burning ethanol without and with BTB) 2: End of https://youtu.be/WsxQvzJqmzM 3: https://youtu.be/Q8Q1irxboCw	Gather more specific evidence of matter changes--oxygen as a reactant (2) and carbon dioxide as a product (3). Also gather more specific evidence of energy changes with IR thermometer	IR thermometer 3 tea candle holders 1000 mL glass beaker 100 mL ethanol or isopropyl alcohol 25 mL bromothymol blue (BTB) 2 small clear plastic cups or small petri dishes Piezo igniter water sticky tack (optional)	In addition to the standard safety considerations, read through the safe handling of ethanol in the laboratory guidance: https://www.nsta.org/safer-handling-alcohol-laboratory. Operate the Piezo igniter only as directed.
Syringe Piston Demonstration https://youtu.be/dvkAowjSytw	Gather evidence that the temperature change results in a force on the piston.	large plastic syringe with cap 1000 mL glass beaker hot water	Follow standard safety considerations.
Fire Syringe Demonstration https://youtu.be/kiYfaaibWL0	Gather initial evidence that a diesel engine can start through compression without a spark.	fire syringe small piece of cotton	Follow standard safety considerations.

Lesson 2 Teacher Reference

CODAP Calculations

Amount of Fuel Needed for 400 Miles of Travel

Researched Values
Example car requires 4,292 BTU/vehicle-mile
Average number of miles per tank = 400 miles/tank

Step 1: Calculate # of BTUs in one fuel tank
4,292 BTU/vehicle-mile x 400 miles/tank = 1,716,800 BTU/tank

Step 2: Multiply each inverse of Fuel's BTU per gallon by the BTU per tank (Step 1)*
x gal/BTU x 1,716,800 BTU/tank = theoretical # of gallons in vehicle tank needed to travel 400 miles

*Compressed natural gas's energy per unit was reported in pounds; therefore, volume was calculated using the density of each fuel.

Step 3: Calculating GGE
Gasoline Gallon Equivalent = BTU of Alternative Fuel per gal / BTU of Gasoline per gal
or
Gasoline Gallon Equivalent = BTU of Alternative Fuel per lb / BTU of Gasoline per 6 lb*
1 gallon of Gasoline = 6 lb of gasoline

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Lesson 2: Answer Key 1

Progress Tracker Key

Criteria to evaluate fuels and transportation decisions	Constraints to consider when evaluating fuels and transportation decisions
Lesson 1 Lowest CO_2 emissions possible Highest energy released Low other pollutants Compatibility with existing vehicles **Lesson 5** Minimize land, fossil fuel, and other resources to produce fuels **Lesson 8** More energy or fuel-efficient vehicles when possible **Lesson 9** Should require minimal use of environmentally hazardous mining Materials should be recyclable if possible **Lesson 10** Charging should be accessible Non-carbon dioxide greenhouse gases should be emitted as little as possible **Lesson 11** Minimize radioactive or other harmful waste	**Lesson 1** Must allow types of vehicles we use now (personal vehicles, public transit vehicles, big vehicles for moving stuff, planes, boats) to continue working Must be affordable **Lesson 2** Fuel must burn at appropriate temperature for engine **Lesson 9** Human rights must be protected during production **Lesson 11** Must fit on vehicles and be safe to handle when refueling

The goal in this unit is not for students to take particular positions on given fuels. As long as students are taking into account a variety of criteria and constraints, including the need to lower carbon dioxide emissions and protect people and the environment in other ways, they may take any positions they wish. Therefore, the second and third columns of the table below are intended as ideas that students are likely to say, rather than those that they are required to say. Under *Engineering implications*, students are asked to consider only one of the three engineering goals, but likely responses for all three are provided for the teacher.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	Engineering implications Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
Lesson 2: Carbon-based fuels are burned to release energy. All carbon-based fuels react in a specific way, where oxygen is combined with the fuel and energy is added to release energy and produce carbon dioxide and water vapor. This is called a combustion reaction. When this takes place in the cylinder system of an engine, the hot gasses in the cylinder push on the piston, causing it to move. The piston is connected to the wheels through several different components in the vehicle. We saw this with investigations and models where we traced energy and matter.	Carbon-based fuels release carbon dioxide when burned. That is one of the reaction products, so another fuel would be needed if the goal was to emit no carbon dioxide. Gasoline and diesel have relatively high energy released. Different fuels burn at different temperatures, so you need one that burns at the right temperature for the engine.	Avoid: Avoid fuels with low energy released values as they don't provide enough energy to move vehicles greater distances. Shift: Look at using diesel or biodiesel because they have higher energy released values but produce less CO_2 than gasoline. Improve: Find a way to minimize matter outputs while maximizing energy outputs.
Lesson 5: When bonds form, energy transfers from the field to particles. The energy in fossil fuels and in biofuels comes from the sun. There are advantages and disadvantages to both fossil fuels and biofuels. We figured this out from modeling and engaging with arguments that traced energy.	Fossil fuels have higher energy released and are already compatible with most vehicle types. There is already infrastructure for the widespread use of fossil fuels, but they produce more carbon dioxide emissions as well as other forms of pollution. Biofuels have lower emissions and pollution, but also lower energy released. They are also not as available as fossil fuels and require land to grow. They could become a better option in the future because of a decreased need for cropland and associated carbon dioxide emissions to grow them.	Avoid: Both fuels where possible. Fossil fuels especially because they cause more pollution and carbon emissions. But biofuels use land that could otherwise be used to grow crops, so we don't want to use too much of those either. Shift: To biofuels where possible, as a lower carbon alternative to fossil fuels. Or shift to different forms of transportation that don't require either. Improve: Use less land or land more responsibly for growing feedstocks, and/or improve the feedstocks used for biofuels. Use more energy efficient transportation options.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	Engineering implications Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
Lesson 7: We used a sim to figure out that, at least in the marble system, it seems like we get more energy out of the reactions than we put in when the bond that forms is stronger, and when the bond that breaks is stronger it takes more energy to start the reaction than we get out.	Carbon-based fuels must have high energy released values because of the bonds that break compared to the bonds that form.	Avoid: Excess trips when possible. Shift: To fuels with higher energy released and lower carbon dioxide emissions. Improve: Whatever fuel we need, it would seem like it should have stronger bonds formed than broken.
Lesson 8: CO_2 production rates vary by fuel type and by size of vehicle. The math showed that fuels with more carbons produce more CO_2, and the mass of CO_2 can be greater than the mass of the fuel! Larger vehicles like trucks or semis that run on diesel or biodiesel will produce the most CO_2.	We need to shrink the size of our vehicles to optimize fuel efficiency. We need to drive less. We need to produce and use fuels that produce less CO_2.	Avoid: Low-efficiency vehicles with tiny cargo loads (big SUVs or trucks with few people in them, school buses running routes with only 6 kids, etc.) Shift: Walk and bike when we can, shift to fuels with less carbon. Improve: Automotive design so that vehicles are more efficient and optimized for their type of fuel, or optimized for lower carbon dioxide emission fuels.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	Engineering implications Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
Lesson 9: As we saw in investigations and diagrams, batteries are made of a solution containing ions and two different metals on either side of the solution. The metals need to have different electronegativities which helps attract ions to one side of the solution more than the other. This creates a difference in the concentrations of charges (forces) in the solution. Because of this, there is more energy stored in the fields within the solution which leads to a greater energy output.	Batteries are promising as a fuel, especially because driving EVs with batteries doesn't have any "tailpipe" emissions, unlike all of the fuels we have investigated before. However, it does require the use of more metals and electricity, which could pose other issues. Batteries have to get better for EVs to work more broadly.	Avoid: Avoid personal vehicles (including EVs) when possible, because they are not harmless to the environment. Making and using any kind of vehicle will emit some CO_2 and require the extraction of resources from the environment. Shift: Shift toward EVs because, on the whole, they are becoming increasingly accessible and generally seem better for the environment (even if they aren't perfect). Improve: Improve by creating batteries with better energy output that potentially use less harmful materials. Also, find ways to recycle the materials used to make batteries so we extract from the environment less.
Lesson 10: Hydrogen fuel cells are similar to batteries in that they directly produce electricity and they are similar to engines in that they have inputs (hydrogen and oxygen) and outputs (water). Although they do not produce carbon dioxide, it is a byproduct of producing hydrogen from natural gas (methane). Methane and carbon dioxide are greenhouse gases (GHGs) because they persist in the atmosphere and absorb infrared radiation emitted by the Earth. Compared to non-GHGs, the atoms in methane and carbon dioxide are more able to vibrate. Methane vibrates more than carbon dioxide and it warms the atmosphere ~30 times more than the same amount of carbon dioxide over 100 years.	As a fuel, hydrogen is promising because it can be pressurized to give a high energy released. In a fuel cell, it reacts with oxygen in the air to produce water as the only emission. However, almost all of the hydrogen produced today comes from methane (a greenhouse gas which is prone to leaks) and carbon dioxide is produced as a by-product. Fuel cells would probably not be compatible with existing vehicles because hydrogen is a gas, not a liquid like current fuels. Hydrogen filling stations are even more rare than charging stations.	Avoid: Producing hydrogen from reactants that produce carbon dioxide as a by-product or are GHGs themselves and may contribute to emissions. Shift: Produce more hydrogen from water using renewable sources of electricity. Provide more hydrogen refueling stations. Improve: Methods to produce hydrogen that do not also emit GHGs.

What we figured out (and how)	Given what we figured out, what can we now say about this lesson's fuel(s) given the criteria and constraints?	**Engineering implications** Explain how what we figured out helps us think about *Avoiding* excess fuel use, *Shifting* transportation, **OR** *Improving* the fuels used in vehicles.
Lesson 11: We saw from models and data that uranium releases energy through fission. The nucleus is hit with neutrons and breaks up. Energy is released from the electric field between positively charged nuclei as they repel. We also read about how nuclear waste is hazardous to living things for thousands of years. It must be stored and transported very carefully to prevent unwanted contamination of the environment.	The cost of building safe nuclear reactors is very high. It doesn't make sense to use uranium as fuel in the more common forms of transportation.	Avoid: Unsafe storage of nuclear materials. Shift: To safer handling practices and plans for waste. Improve: Safety technology for nuclear technology, although nuclear engineers nowadays are doing the most to keep it safe. Control rods are critical to safe fission and have killed people when not used properly. Also improving waste storage technology so we don't have to blow up sacred lands and mountains just to bury our waste.

Lesson 4 Teacher Reference

Building Marble Equipment

General safety protocols for demonstrations and hands-on activities:

- Conduct a hazards analysis and risk assessment of all set-ups for materials and review safety action to be taken before working on materials.. Prepare a list of the significant hazards in the procedure and identify the controls necessary to minimize them.
- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- An eyewash station is required in case of a splash with hazardous chemicals (glue) or contact with physical hazards such as hot glue guns..
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Use caution when working with physical hazards such as projectiles, marbles on the floor and trip/slip fall hazards.
- Use caution when working with a hot glue gun! Can burn skin on direct contact.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.

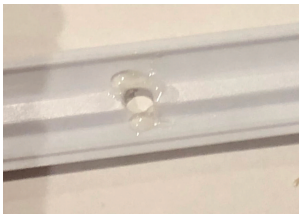
The directions below outline the setup of the materials needed for the investigations in **Lessons 4-7**, all of which use magnet marbles, metal marbles, glass marbles, rulers, box stands, glue gun, and glue sticks. Some of the materials you develop for a lesson will be used in a subsequent lesson.

Lesson 4: Marble Interactions Investigation and Demonstration

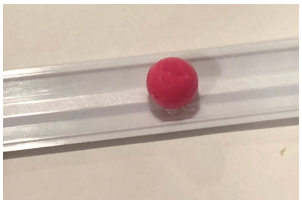
You will need the following materials to create the 7 setups students will use in this lesson:

- 14 rulers
- 21 box stands
- 7 regular magnet marbles
- 7 metal marbles
- 7 glass marbles
- Hot glue gun and glue sticks
- Small flathead screwdriver
- Level
- Tape
- Pieces of scrap paper

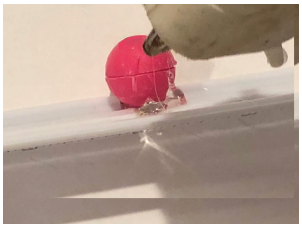
Add hot glue to the bottom side of a ruler around the edge of the center hole, which is below the 15-cm location. Try not to get glue in the hole. If you do, peel off any hardened glue sticking through to the other side of the ruler in the next steps to ensure a smooth surface for marbles to roll.



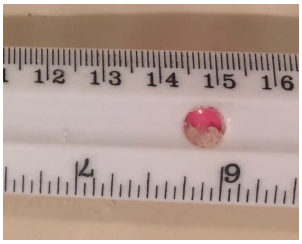
Quickly set a regular magnet marble against the glue so that its equator is parallel to the "track" and either of its poles is facing up. Hold it in place for about 30 seconds, which should be long enough for the glue to cool and set.



Add extra glue around the edges of the marble to secure it to the ruler.

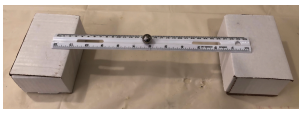


Check to make sure there is no glue on the other side that would interfere with a marble rolling along the groove above the hole. If there is glue sticking through, peel and chip it off with the end of a flathead screwdriver.

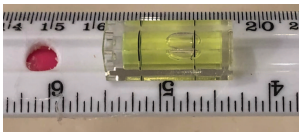


What you built is referred to as a *magnet marble and ruler system.* Repeat the previous steps to build 7 of these in total.

Position two boxes about 25 cm (10 in.) apart, with their shortest edge vertical. Place a magnet marble and ruler system across the gap between the boxes, with about 1" of the ruler on each box. Place the metal marble above the magnet marble (at 15 cm).



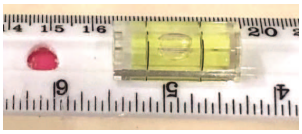
Place a level on the horizontal ruler. If the bubble in the level is not centered between the two black lines, it is not level.



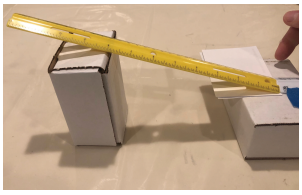
To correct an unlevel horizontal ruler, slide some small pieces of scrap paper or index cards under either the left or right edge of the ruler until the bubble in the level is centered between the two black lines.



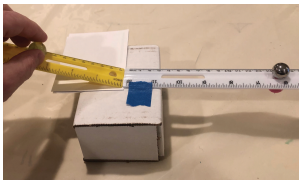
This is what the bubble should look like when it is level. Remove the level from the horizontal ruler. Secure the ruler in place with tape.



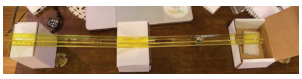
Add a third box with its longest edge vertical, so that when you lay a second ruler against it and the left edge of the magnet marble and ruler system, the ruler leans against the third box at about the 8-inch mark. The edge of the angled ruler will be lower than the horizontal ruler it is against. This creates a problem for smooth rolling of the glass marble off the angled ruler and onto the flat one. To correct this, slide some small pieces of scrap paper or index cards under the edge of the angled ruler until it is at (or just above) the edge of the horizontal ruler.



Test roll a glass marble down the angled ruler to ensure there is no longer a "speed bump" between the rulers that will derail the marble. Students will complete the investigation by placing the glass marble at various heights on the ruler and letting go. You may want to practice this from the greatest height on the angled ruler to make sure that the glass marble remains in the groove of each ruler. If needed, correct any misalignment between the rulers and secure them in place with tape.



If available, have an open box or other object that could be used to catch the marbles as they exit the system. You could also choose to open the last box to catch the marbles. If you do this, ensure that the horizontal ruler is still level. This will help prevent marbles from falling onto the floor and causing slips and falls.



Lessons 5-7: Build Stronger Magnet Marbles

You will need the following materials to build the 35 stronger magnet marbles students will use in **Lessons 5-7:**

- 35 regular magnet marbles
- 140 neodymium magnets (7mm x 3mm)
- Permanent marker
- Slip-joint pliers
- Small flathead screwdriver
- Cyanoacrylate glue
- Hot glue gun and glue sticks

Note: If possible, choose one color of magnet marble to use when building the stronger magnet marbles. This will ensure consistency in student noticings as they discuss patterns from the investigations in **Lesson 7**. Images in **Lesson 7** have the stronger magnet marbles (oxygen) as blue and the regular magnet marbles (carbon) as white. Even if you do not have magnet marbles that are all the same color, that is okay because you will add marks on the stronger magnet marbles in the steps below to help distinguish them from the regular magnet marbles in later lessons.

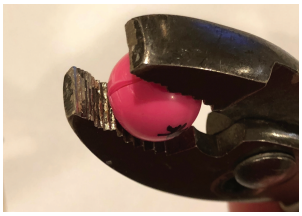
Each magnet marble has a seam where the two halves of the plastic sphere join. This will be referred to as the marble's "equator." The locations of the fingers in this image will be referred to as the "poles" of the marble (like the poles of Earth).



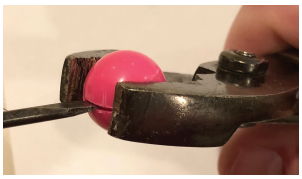
Mark both poles of each stronger magnet marble with a permanent marker. This will help you keep track of them.



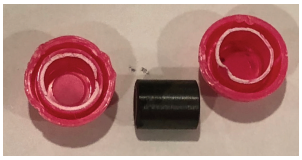
Open the slip joint on a pair of pliers and place a regular magnet marble between the jaws so that the poles are facing outward and the equator is in line with the central axis of each plier jaw. Squeeze hard until you hear a crack. Open the jaws of the pliers and rotate the marble about 30 degrees and squeeze again. Repeat this six times. You now will have worked around the entire equator of the magnet marble and broken open an internal seal, allowing you to separate both halves of the plastic shell.



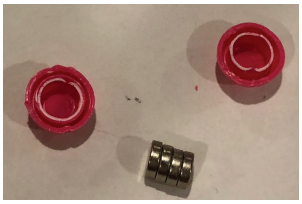
Squeeze the pliers until there is an opening in the equator large enough to slip in a flathead screwdriver. Push in the screwdriver to pry apart the two halves and twist it to leverage open the plastic shell.



Remove the ceramic magnet from the center of the plastic shell.



Prepare a stack of 4 neodymium magnets (7mm x 3mm) to swap in.



Place a bead of hot glue on one end of the stack of magnets.



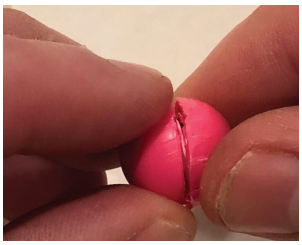
Place the stack of magnets in the center holder of either plastic half shell, hot glue-side down. Push down on the stack until the hot glue sets.



Apply a bead of cyanoacrylate glue around the center holder of the other plastic half shell.



Bring both plastic halves together with the stack of neodymium magnets in their center. Twist the halves until they line up along the edges where they broke apart. Try to find this location within 30 seconds, before the glue sets. If you do not find it, repeat the previous step and try again.



Place the poles of the magnet marble against each jaw of the pliers and use them to lightly squeeze the plastic halves together for 30 seconds so that there is no longer a gap at the equator. After 30 seconds the marble should be fully resealed and ready to use as a manipulative.



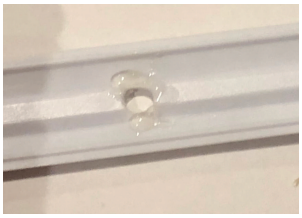
What you built is referred to as a *stronger magnet marble.* Repeat the previous steps to build 35 of these in total.

Lesson 5: Marble Interactions Investigation and Demonstration

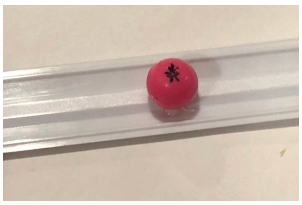
You will need the following materials to create the *stronger magnet marble and ruler system* that you will use in this lesson:

- 1 ruler
- 1 stronger magnet marble (See previous instructions on how to build these.)
- Hot glue gun and glue sticks
- Small flathead screwdriver

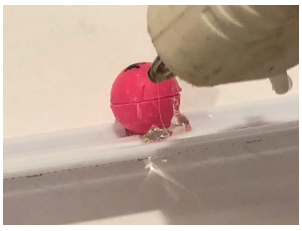
Add hot glue to the bottom side of a ruler around the edge of the center hole, which is below the 15-cm location. Try not to get glue in the hole. If you do, peel off any hardened glue sticking through to the other side of the ruler in the next steps.



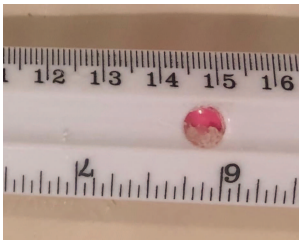
Quickly set a stronger magnet marble against the glue so that its equator is parallel to the "track" and either of its poles is facing up. Hold it in place for about 30 seconds, which should be long enough for the glue to cool and set.



Add extra glue around the edges of the marble to secure it to the ruler.



Check to make sure there is no glue on the other side that would interfere with a marble rolling along the groove above the hole. If there is glue sticking through, peel and chip it off with the end of a flathead screwdriver.



What you built is referred to as a *stronger magnet marble and ruler system.*

Lesson 6: Two Magnet Marble Interactions Demonstration

You will need the following materials to create the setup you will use in this lesson:

- 2 rulers
- 3 box stands
- 1 metal marbles
- 2 glass marbles
- 2 regular magnet marbles
- Hot glue gun and glue sticks
- Level
- Tape
- Pieces of scrap paper

If you choose to have extra setups available or have students engage in the investigation directly, you will need to scale the materials available accordingly.

Add hot glue to the bottom side of a ruler around the edge of the center hole, which is below the 15-cm location. Try not to get glue in the hole. If you do, peel off any hardened glue sticking through to the other side of the ruler in the next steps to ensure a smooth surface for marbles to roll.



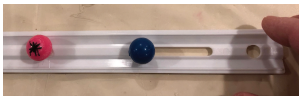
Place a regular magnet marble over the hole so that its equator is parallel to the "track." Hold it in place for about 30 seconds, which should be long enough for the glue to cool and set.



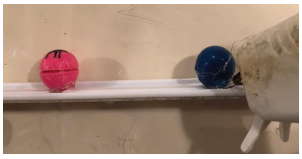
Add a spot of hot glue on the bottom side of the ruler under the 22-cm location. This will also be close to the edge of one of the grooves in the ruler.



Quickly set a regular magnet marble against the glue so that its equator is parallel to the "track." Hold it in place for about 30 seconds, which should be long enough for the glue to cool and set.



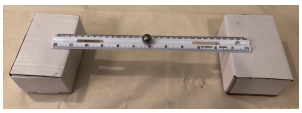
Add extra glue around the edges of both magnet marbles to secure them to the ruler.



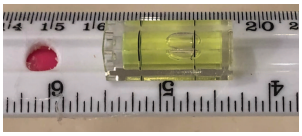
What you built is referred to as a *two magnet marble and ruler system.*

Lesson 6: Two Magnet Marble Interactions Investigation Continued

Position two boxes about 25 cm (10 in.) apart, with their shortest edge vertical. Place a two magnet marble and ruler system across the gap between the boxes, with about 1" of the ruler on each box. Place the metal marble above the first magnet marble (at 15 cm).



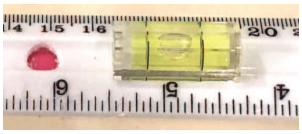
Place a level on the horizontal ruler. If the bubble in the level is not centered between the two black lines, it is not level.



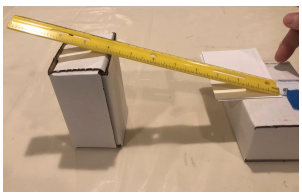
To correct an unlevel horizontal ruler, slide some small pieces of scrap paper or index cards under either the left or right edge of the ruler until the bubble in the level is centered between the two black lines.



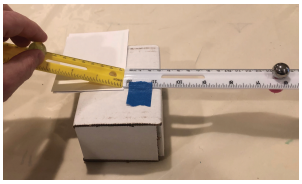
This is what the bubble should look like when it is level. Remove the level from the horizontal ruler. Secure the ruler in place with tape.



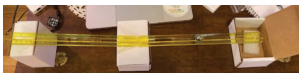
Add a third box with its longest edge vertical, so that when you lay a second ruler against it and the left edge of the two magnet marble and ruler system, the ruler leans against the third box at about the 8-inch mark. The edge of the angled ruler will be lower than the horizontal ruler it is against. This creates a problem for smooth rolling of the glass marble off the angled ruler and onto the flat one. To correct this, slide some small pieces of scrap paper or index cards under the edge of the angled ruler until it is at (or just above) the edge of the horizontal ruler.



Test roll a glass marble down the angled ruler to ensure there is no longer a "speed bump" between the rulers that will derail the marble. Students will complete the demonstration by placing the glass marble at various heights on the ruler and letting go. You may want to practice this from the greatest height on the angled ruler to make sure that the glass marble remains in the groove of each ruler. If needed, correct any misalignment between the rulers and secure them in place with tape. Breaking a stronger bond may require a student to increase the angle of the ruler and hold it higher than it would be when leaning on the taller box.



If available, have an open box or other object that could be used to catch the marbles as they exit the system. You could also choose to open the last box to catch the marbles. If you do this, ensure that the horizontal ruler is still level. This will help prevent marbles from falling onto the floor and causing slips and falls.



Lesson 7: Bond Strength Investigation

Set aside the following supplies for each group of 2 students:

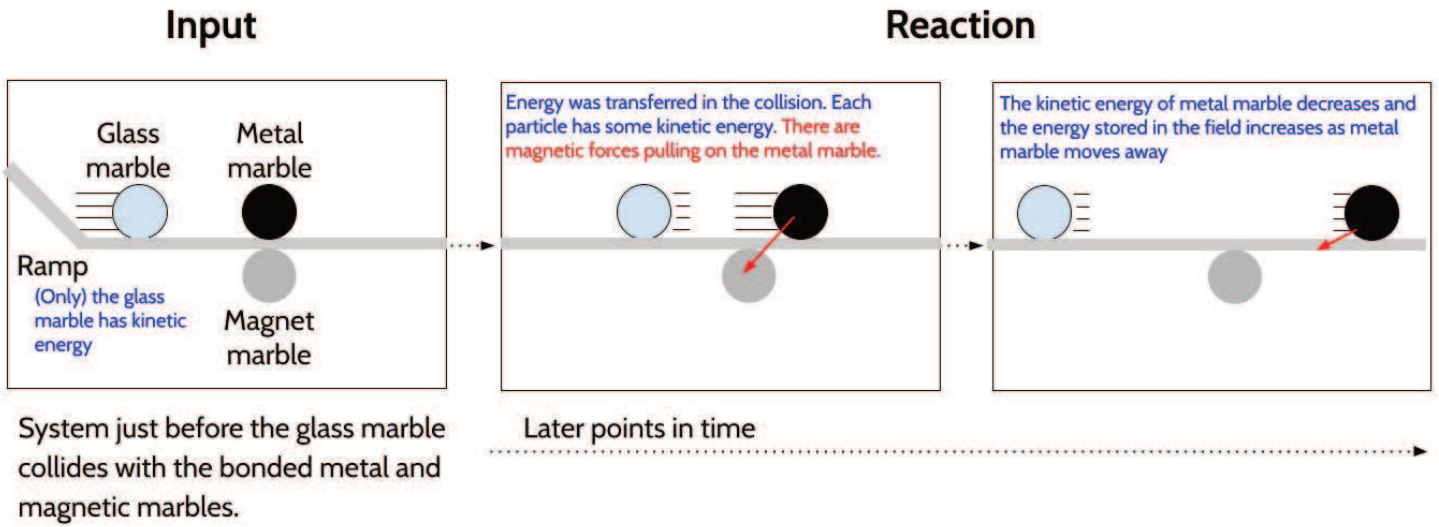
- 2 stronger magnet marbles, each representing an oxygen atom (See previous instructions on how to build these.)
- 2 regular magnet marbles, each representing a carbon atom
- 2 metal marbles, each representing a hydrogen atom
- 2 paper clips, each representing a pair of shared electrons in a bond

Additionally, there is a quick demonstration using some of the marbles. This requires only the following supplies: 2 stronger magnet marbles, 2 regular magnet marbles, and 2 paper clips. Reuse some of these supplies in the student groups.

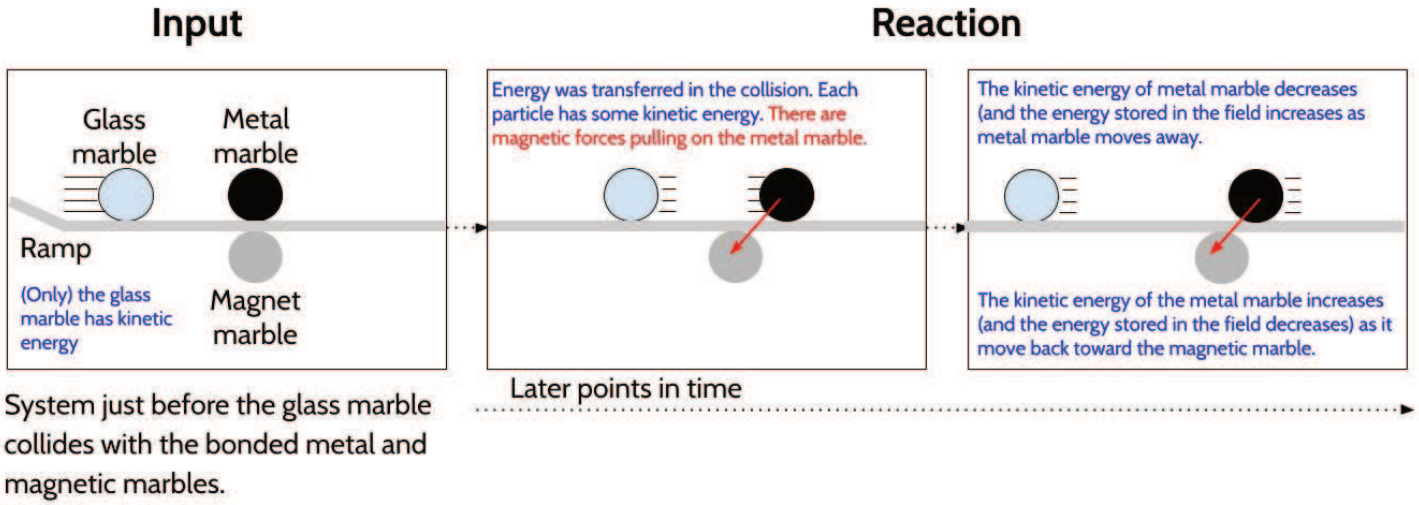
Lesson 4: Answer Key 1

Energy & Forces Key

Result 1: *Bond is broken*



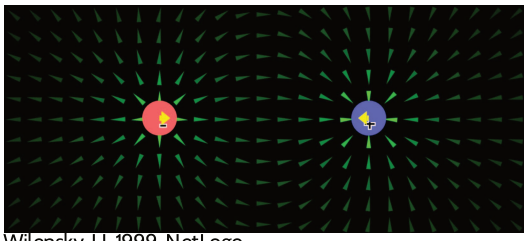
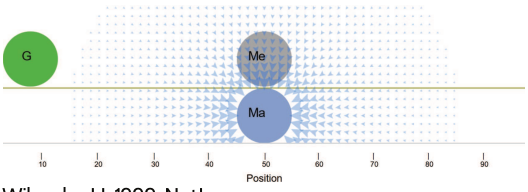
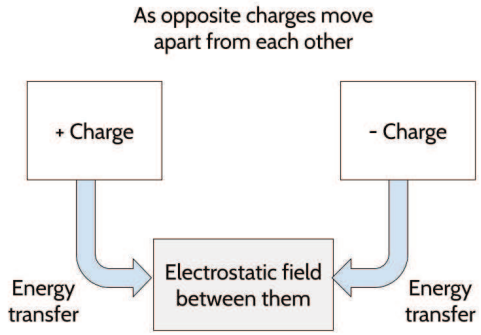
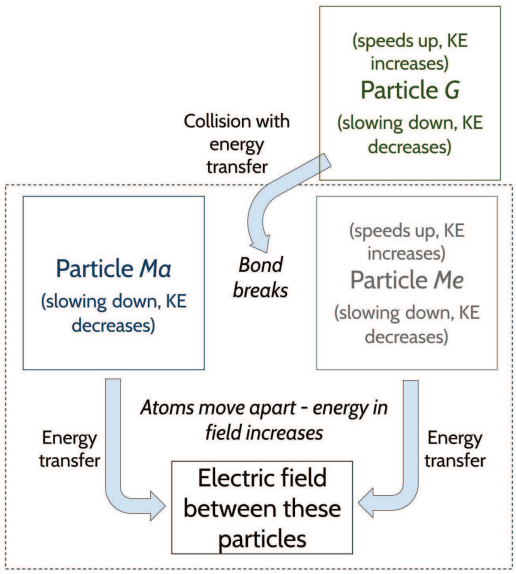
Result 2: *Bond is not broken*



Lesson 4: Answer Key 2

Mapping Between Models Key

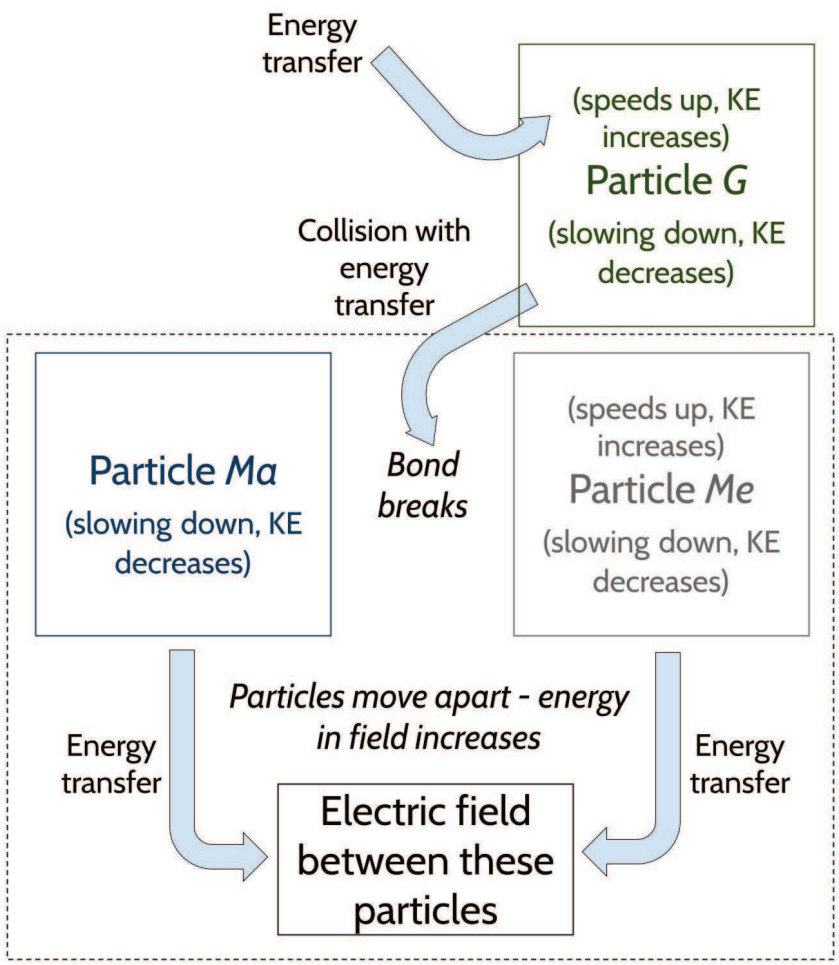
Instructions: We have used different models to make sense of phenomena involving energy. To make sense of energy transfers in fuel combustion, use the table to map between the model of charges moving apart that you developed from the simulation in *Electrostatics Unit*, and the simulation of a bond breaking (Result 1) from this lesson. Leave the energy transfer model for Result 1 until the end.

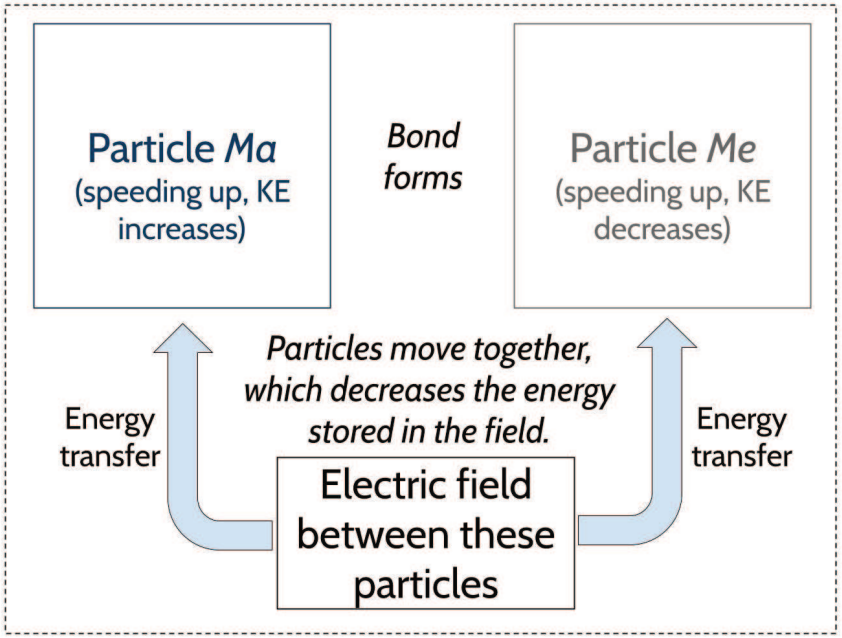
	Charges moving apart *Simple example of energy transfer and fields*	**Bond breaking (Result 1)** *Similar situation*
Simulation	 Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.	 Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.
System components	Positive charge Negative charge Electric field between them	Atom 1 (or metal marble) Atom 2 (or magnet marble) Electric (or magnetic) field between them
Energy transfer model		(Leave blank for now) 
Why is energy needed to separate the particles?	One particle is positively charged and the other is negatively charged, so there is an attractive force between them.	The atoms are bonded because of a force between them (or, The marbles are stuck together because of the force between them).
Where does the energy come from to separate the particles?	From the person changing the particles' positions in simulation	From Particle 3 (or the glass marble coming in)

Where does the energy go when the particles are separated?	Into the electric field between the particles	Into the electric field between the particles
How do the forces change as the particles separate?	The force got weaker as the particles moved farther apart.	The force got weaker as the particles moved farther apart.
How does further separation affect the kinetic energy of the particles? the energy stored in the field between the particles?	Kinetic energy was lower when the particles were farther apart, and the energy in the field was higher.	Kinetic energy decreased and energy in the field increased.

When you have finished the mapping: The mapping should help us see connections between energy transfers when charges move in a field and when bonds break. Return to the top and draw an initial energy transfer model that explains what happened to cause the bond to break in Result 1.

Bonds Breaking/Forming





Lesson 5 Teacher Reference

Electronic Exit Tickets

Why student Electronic Exit Tickets?

Student Electronic Exit Tickets are a great tool for collecting data from students to inform instruction. Having students take these exit tickets electronically helps to quickly aggregate data so that students can analyze results to guide and inform the direction of their future work.

How to use student Electronic Exit Tickets

Attending to Equity
Some students may benefit from completing the Electronic Exit Tickets on a printed version. Complete the steps below to create a copy of the Electronic Exit Ticket. Once you have created a copy in your own Google Drive, click on the 3 dots in the upper-right corner of the form, next to the SEND button. This should give you an option to print a paper copy of the Electronic Exit Ticket.

1. Select the link for the survey that corresponds with the lesson you are teaching. In *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)* there are two Electronic Exit Ticket assessments, in Lessons 5 and 11.
    - Lesson 5: https://docs.google.com/forms/d/1WLFipq9FUZx8d4wat28iDdBPdgSK-0SV0s2_OQV3UDI/copy
    - Lesson 11: https://docs.google.com/forms/d/1Hquul2ebA8b9R0GHxNwPiok5ZRZCh1lhQSlbEx9LIn8/copy

Spanish versions are available here:

- Lesson 5: https://docs.google.com/forms/d/10-32c_-jfqE_3dq2jAFdJTSIpLt0XMr95RpjRFdy8BO/copy
- Lesson 11: https://docs.google.com/forms/d/1IvTHWPHdg9m_pB9MZzz06X--VzD4IOsOR-zFPik3Eoc/copy

Lesson 9 contains a similar Google Form for students' designs: **Missed Video/Url ID (OP.CE.VID.L9.101) in tag**
Spanish: **Missed Video/Url ID (OP.CE.VID.L9.103) in tag**

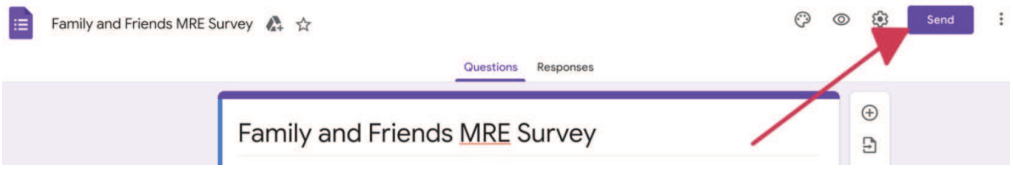
2. When you select the link, you will be asked to make a copy in your own Google Drive.



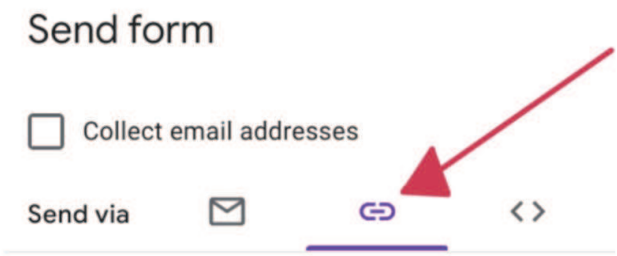
3. The student survey will open in your own Google Drive.



4. Select the “Send” button in the upper-right corner to get a link to give to students.



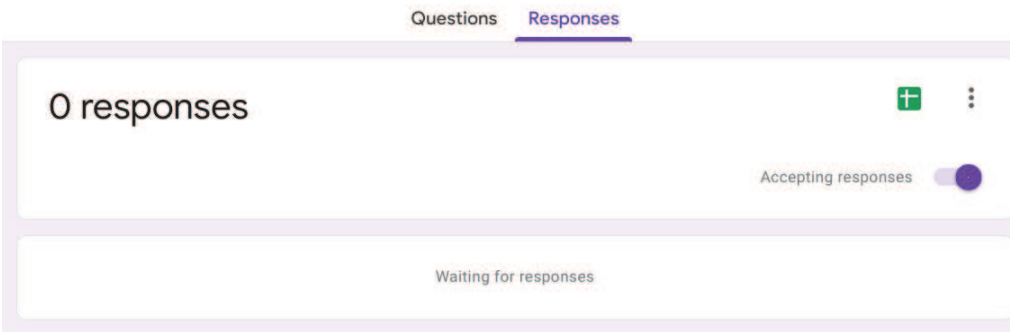
5. In the “Send via” panel, select the middle icon if you wish to send the survey via a link.



6. Copy the link provided or select the “Shorten URL” box and then copy the link. This second option creates a link that will be easier for students to type.



7. Once students submit responses these will appear in your Google Form under ”Responses”. Google will automatically provide you with some visualizations of the responses.



8. If you want to view the data in a spreadsheet format, click the sheet icon to create a Google Sheet. It will automatically populate when students respond to the survey.

9. For each survey, you will need to repeat the process above. You can choose to make a copy of the survey for each of your classes, or use one survey for all of your classes.

Lesson 5: Answer Key

L5 Electronic Exit Ticket

5.A Develop and use multiple types of models that show matter and energy flows into, out of, and within a system as atoms interact in fields to form new chemical bonds. (SEP: 2.4, ~~6.4~~; DCI: ~~PS1.B.1~~, PS3.C.1; CCC: 5.2)			
Where these elements are addressed in this assessment	**2.4 Developing and Using Models** Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.	**PS3.C.1 Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**5.2 Energy and Matter** Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
Q1			
Q2	X	X	
Q3		X	X
Q4	X		X
Q5	X		
Q6			X
Q7			X
Q8			

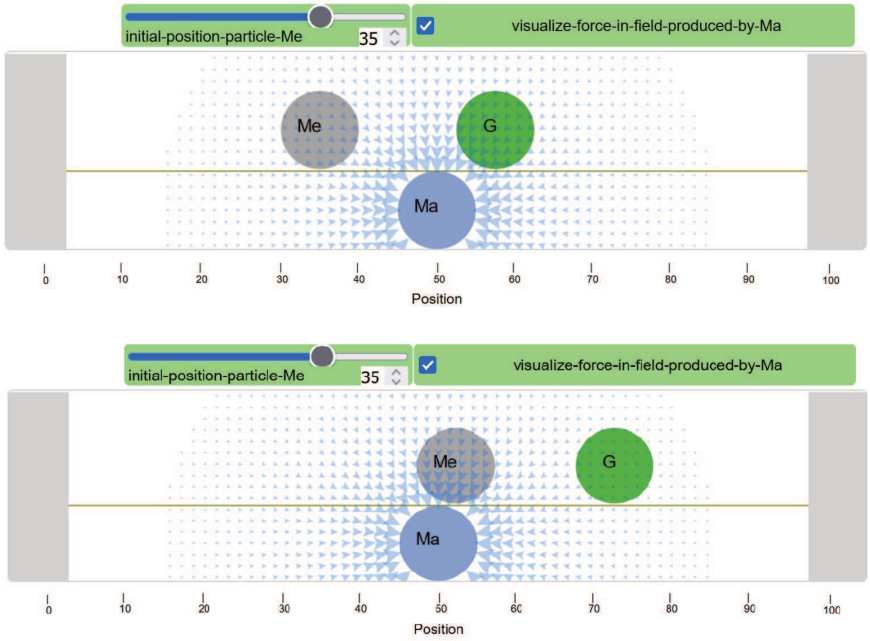
Question 1

What is another phenomenon in which large amounts of energy leave the system? Think about this phenomenon while you answer the questions.

Accept all responses.

Question 2

The screenshots from the simulation (below) show two points in time over which a bond is being formed. Which statement best explains the changes to the energy in the field and kinetic energy of the particles between these two points in time?



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

- Energy is being transferred into the field between Particle *Me* and Particle *Ma*. This causes the kinetic energy of the particles to decrease.
- Energy is being transferred into the field between Particle *Me* and Particle *Ma*. This causes the kinetic energy of the particles to increase.
- Energy is being transferred out the field between Particle *Me* and Particle *Ma*. This causes the kinetic energy of the particles to decrease.
- **Energy is being transferred out of the field between Particle *Me* and Particle *Ma*. This causes the kinetic energy of the particles to increase.**

Correct response: Energy is being transferred out of the field between Particle *Me* and Particle *Ma*. This causes the kinetic energy of the particles to increase.

Rationale for correct response: Students should recall that attractive forces result in objects or particles moving together rather than apart, and that the energy stored in the field between opposite charges decreases, or is transferred to the particles, as those particles move closer.

What to do: Remind students to think back to both models they examined in class–the magnet marble and ruler system and the simulation.

Ask students what they observed in the speed of the glass marble/Particle *G* immediately after the bond formed between the metal marble/Particle *Me* and the magnet marble/Particle *Ma*, and how changes in kinetic energy (speed) relate to changes in energy stored in the field.

Question 3

Why did we observe a greater increase of kinetic energy when the metal marble (*Me*) was placed farther from the magnet marble (*Ma*)?

- Attracted particles have greater kinetic energy when they are separated by greater distances. This results in greater kinetic energy when a bond forms.
- Attracted particles have less kinetic energy when they are separated by greater distances. This results in lower kinetic energy when a bond forms.
- There is less energy stored in the field when attracted particles are farther away from each other. This lower amount of energy stored in the field results in greater kinetic energy when a bond forms.
- **There is more energy stored in the field when attracted particles are farther away from each other. This greater amount of energy stored in the field results in greater kinetic energy when a bond forms.**

Correct response: There is more energy stored in the field when attracted particles are farther away from each other. This greater amount of energy stored in the field results in greater kinetic energy when a bond forms.

Rationale for correct response: Students should recall from the simulation that the speed of the metal marble (*Me*) was higher the farther away it was from the magnet marble (*Ma*) in the simulation. Because the metal marble (1) is exposed to fields over a longer period of time and/or distance, the energy transferred from the field to the metal marble (*Me*) is greater than it is at shorter periods of time or distances.

What to do: Remind students of the marbles investigation and simulation, and the observed final kinetic energy when a bond formed from a greater distance. Students can also think back to the simulation they used in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* and may have used this lesson to observe the interaction between energy and charged matter.

Question 4

Consider the models we have used in the last two lessons to explain energy transfers while bonds break and form. What predictions could you make about the overall (net) amount of kinetic energy in the cylinder system before versus after the combustion reaction in an engine takes place?

What to look for in response:

- Students compare energy transfer in bond breaking and bond forming.
- Students consider both the energy that goes into the system to break a bond and the energy that comes out when a bond forms.
- Students cite one or more models in their explanation (physical model, computer model, collision model, energy transfer model).

This prompt is intended to help students think about why their work in Lesson 5 will be important, and should only be a completion grade.

Question 5

Which of the models we used in this lesson (the marbles, the simulation, your drawing) worked best to help you explain the lesson question: *How and why is energy released when we burn carbon-based fuels?* Why? What are the merits of that model that made it the most useful, and what are the limitations of the other models?

What to look for in response: *Note: These could be different for each student.*

- Students should identify which model was most useful to them.
- They should identify the aspects of the model that led to it being most useful. Students may mention how the chosen model illustrates matter and energy changes better than the others.
- They should also explain the limitations of other models that led to them being less useful to students in answering the lesson question.

What to do: If students are struggling to articulate how one model helped them to explain bond formation, spend some time discussing as a class the merits and limitations of each of the models. These could be:

- The marbles model does not let us measure energy changes; it can only give us some idea of qualitative relationships.
- The simulation model lets us make only certain changes, but does allow us to measure energy changes.
- Our drawn models required revisions to help us make sense of the energy changes; we used both of the other models to develop our drawn models and without those, we could not have made accurate drawn models.

Discussion of the limitations of the three models used in the lesson can help students identify which model may have provided more information to help explain the lesson question.

Question 6

How did keeping track of changes in both energy and matter together in the system help you explain the lesson question: *How and why is energy released when we burn carbon-based fuels?*

What to look for in response:

- Students should mention that observing changes in the speed and relative position of the marbles as bonds form prompted them to want to measure changes in energy using a simulation. *Note: At this point, do not expect students to talk about net energy transfer into and out of the system. They will explore this in Lesson 6.*

What to do: If students do not identify any portions of the system, prompt them to identify them (e.g., marbles on the ruler or the particles in the piston cylinder). Tell students that this is important to explain the movement of matter and energy into and out of the system.

It is important to note that students do not need to explicitly discuss where kinetic energy and stored energy are in the system, as that is measuring DCI: PS3.C.1 understandings. Rather, this question is developed so that students think metacognitively about how tracking energy transfers as matter moves into and out of the system (CCC: 5.2) helped them to answer the lesson question.

Question 7

How does what we figured out today about energy transfers in an engine during combustion help you understand and explain the related phenomenon you chose in Question 1? Use your responses to prior questions to help you explain this other phenomenon.

Accept all responses.

Question 8

Name one student who helped you learn today. What did they do?

What to look for in response:

- Students identify another student that helped them.
- Students articulate how that student helped them.

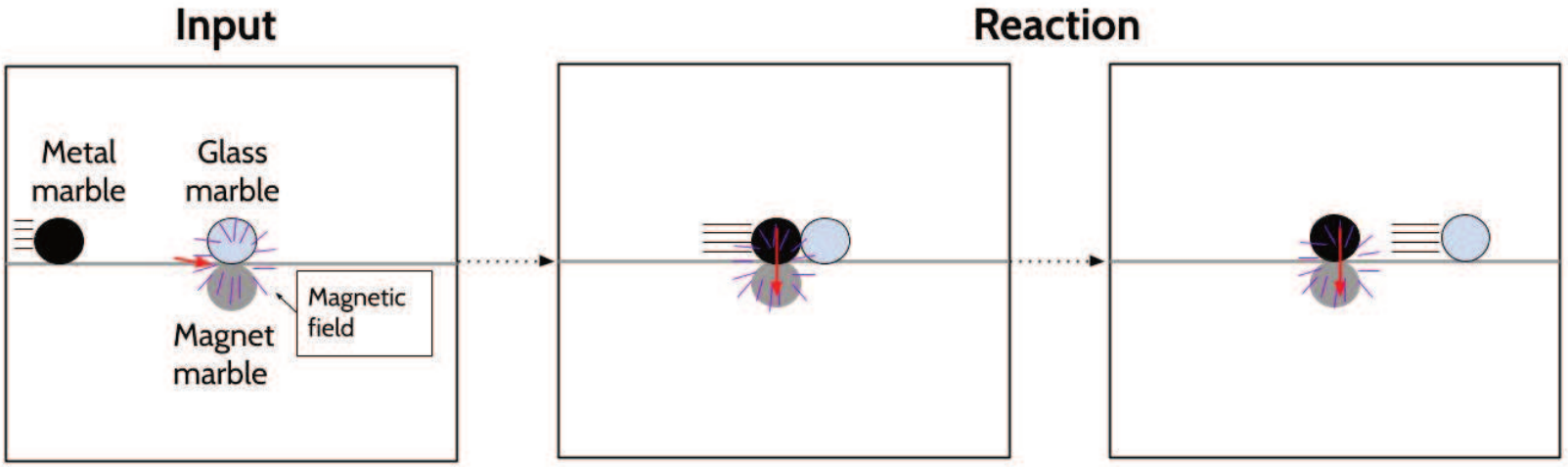
What to do: Depending on student responses, it may be beneficial to revisit the Community Agreements.

- If many students do not name another student, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science and engineering ideas.
- If many students do not explain what the other student did to help them, revisiting the Community Agreements may encourage students to think about what specific agreement the classmate was adhering to that caused them to be helpful.

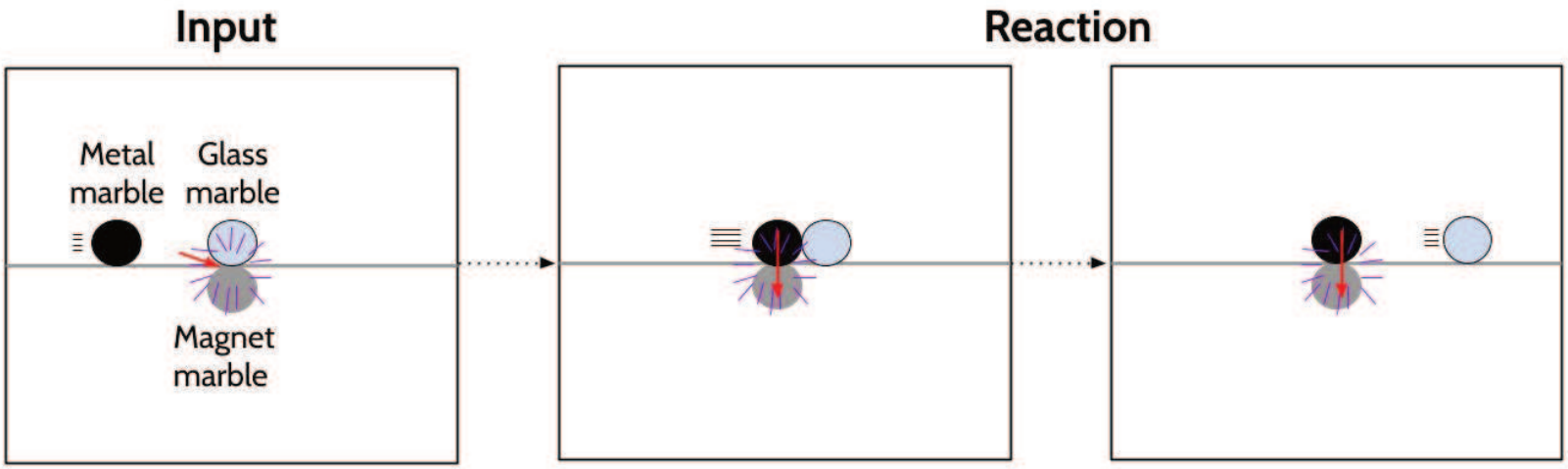
Predicting Energy Changes Key

Directions: Add to the model templates below to show changes in matter, energy, and forces before, during, and after a bond forms.

Model 1 (farther distance):



Model 2 (closer distance):



System just before the metal marble bonds with the magnet marble.

There are magnetic forces pulling on the metal marble.
Energy is transferred from the field to the metal marble.

Later points in time

Less energy transfers from the field to particles; metal marble speeds up, but less this time.

Bond forms between magnet marble and metal marble.
Metal marble transfers KE to glass marble and glass marble rolls away (energy is released). Less energy is transferred to glass marble because metal marble is not moving as fast.

Data Table

Data Table

Collect data using https://openscied-static.s3.amazonaws.com/HTML+Files/Forming+Bonds+PR.html and record below.

Starting Position of Particle *Me*	Energy Stored in Field at Start	Total Kinetic Energy at Contact
10	3.67	3.62
20	3.3	3.25
30	2.65	2.6

Model Reflection

Reflect: Was your prediction about the relationship between distance and energy output correct?

Accept all answers.

What did you observe in the simulation that supports or refutes your prediction?

When Marble B started farther away, there was more kinetic energy when the bond formed. Marble B had greater kinetic energy when it hit Marble 1, and Marble 1 rolled away with greater kinetic energy.

You used two different models to investigate bond formation: the magnet marble and ruler system, and the simulation. What are the merits and limitations of each of these for modeling, investigating, and explaining energy transfer during bond formation?

Accept all answers. Look for reasoning such as:

- Students could not quantify energy with the rulers and marbles, but they could with the simulation.
- Students had more control over starting conditions in the simulation.
- Students may have preferred to be able to directly manipulate the magnet marble and ruler system.

Use your models and data to assess the claim, "The energy released when carbon-based fuels burn is due to bond formation."

If you are unsure where to start:

1. State the evidence you have available (models and data).
2. Explain whether this evidence does not support the claim, partially supports it, or fully supports it.

Look for reasoning such as:

- Energy in the field decreased and energy in particles increased when bonds formed.
- The rolling away of the glass marble indicates a release of energy.

Lesson 6: Answer Key 1

Breaking/Forming Key

Investigation Results: Breaking and Forming Bonds 2 Simulation

Access the simulation at https://openscied-static.s3.amazonaws.com/HTML+Files/Breaking+%26+Forming+Bonds+PR2.html.

Magnet *M1* strength	Magnet *M2* strength	Input: Initial kinetic energy (total)	Observations	Output: Final kinetic energy (total)	NET change in kinetic energy (increase, decrease, or no change)
3	3	2.0	The metal marble wobbles and the bond is barely broken.	2.0	No change
4	3	2.0	The bond is broken. There is some wobble with the new bond that forms.	1.2	Decrease (by about 0.8)
3	4	2.0	The bond breaks easily. There is some wobble with the new bond that forms.	2.5	Increase (by about 0.5)
2	2	1.15	The metal marble wobbles and the bond is barely broken.	1.15	No change
3	2	1.15	The first bond never breaks. The glass marble isn't moving fast enough.	0.65	Decrease (by about 0.5)
2	3	1.15	The bond breaks easily. There is some wobble with the new bond that forms.	1.7	Increase (by about 0.55)

Use the final column of net change to determine patterns to predict when energy is released by a reaction. What patterns do you notice...

- when the net change in kinetic energy is an increase?

The bond that forms is stronger than the bond that breaks.

- when the net change in kinetic energy is a decrease?

The bond that breaks is stronger than the bond that forms.

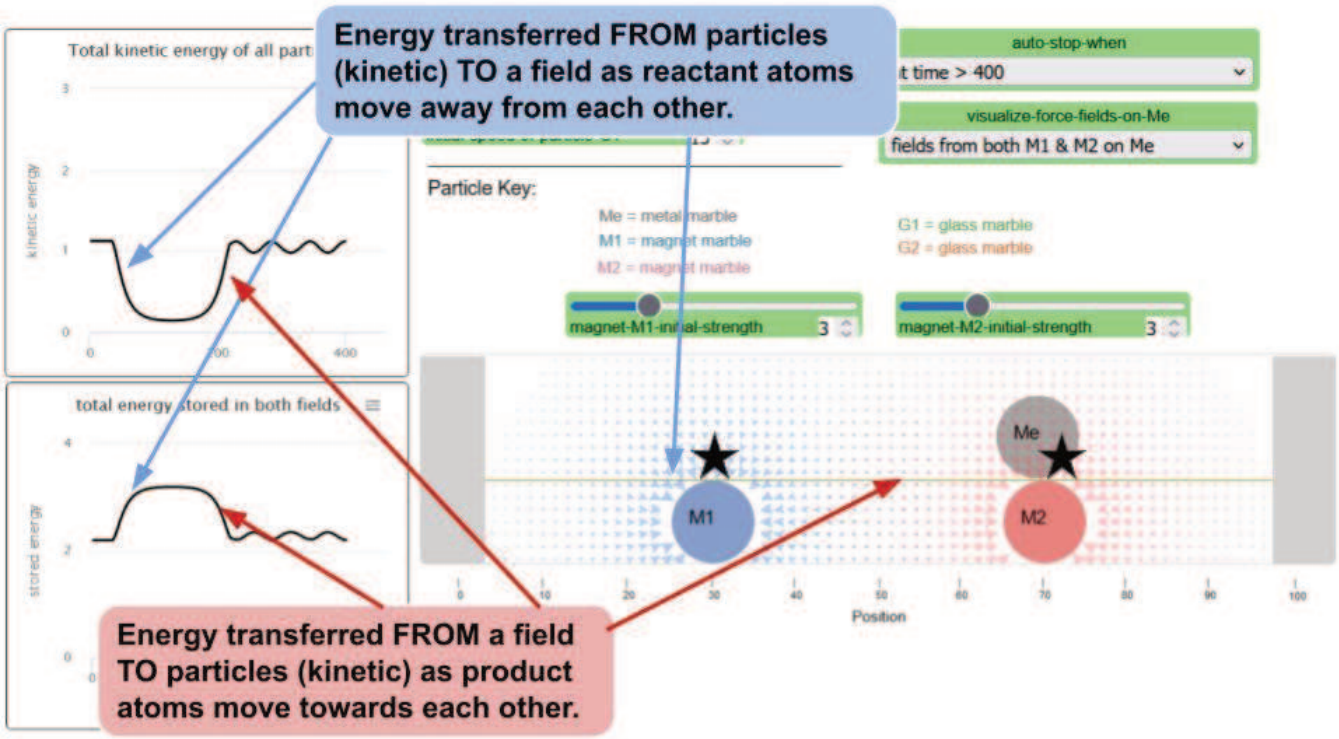
- when there is no net change in kinetic energy?

The bond that breaks is about the same strength as the bond that forms.

Lesson 6: Answer Key 2

Modeling Energy Key

Scenario 1: The bond broken between *Me* and *M1* and the bond formed between *Me* and *M2* are of equal strength.



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

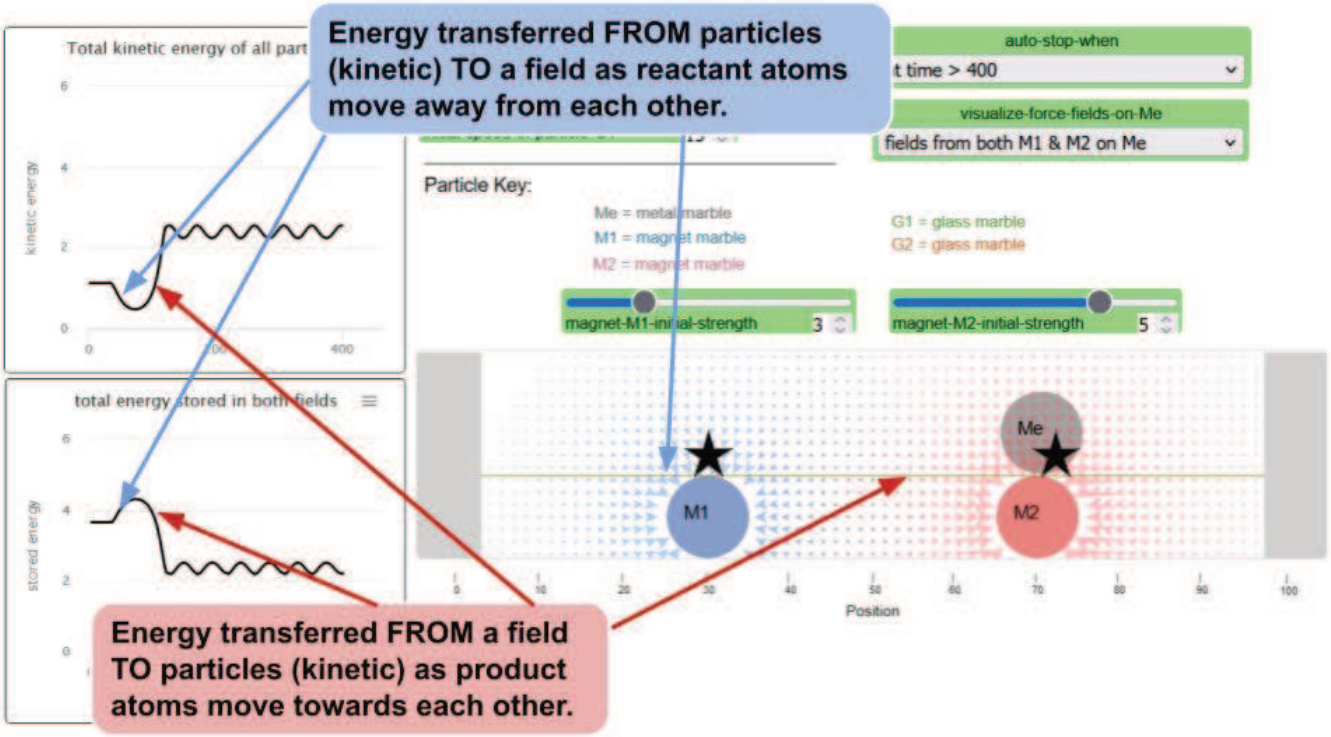
1. Where are the moments that energy is transferred? Mark them with a star (☆) in the screenshot above.

2. Label each star to identify where the energy is transferred FROM and TO. For example: "Energy is transferred FROM ___ TO ___" where the blanks contain "particles" or "fields between particles."

3. What evidence is there in the model that shows you that energy is conserved?
It looks like the kinetic energy and energy in the field are both about the same after as before, so energy is conserved.

4. If this reaction happened in an engine, do you think it would or would not be able to cause the vehicle to move? How do you know? Explain your reasoning in terms of the NET energy transfer into versus out of the system.
The vehicle would not move because you need particles moving around more/faster after combustion than before, and that does not look like the case here. In fact it looks like there is no net energy transfer into or out of the system.

Scenario 2: The bond broken between *Me* and *M1* is weaker than the bond formed between *Me* and *M2*.



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

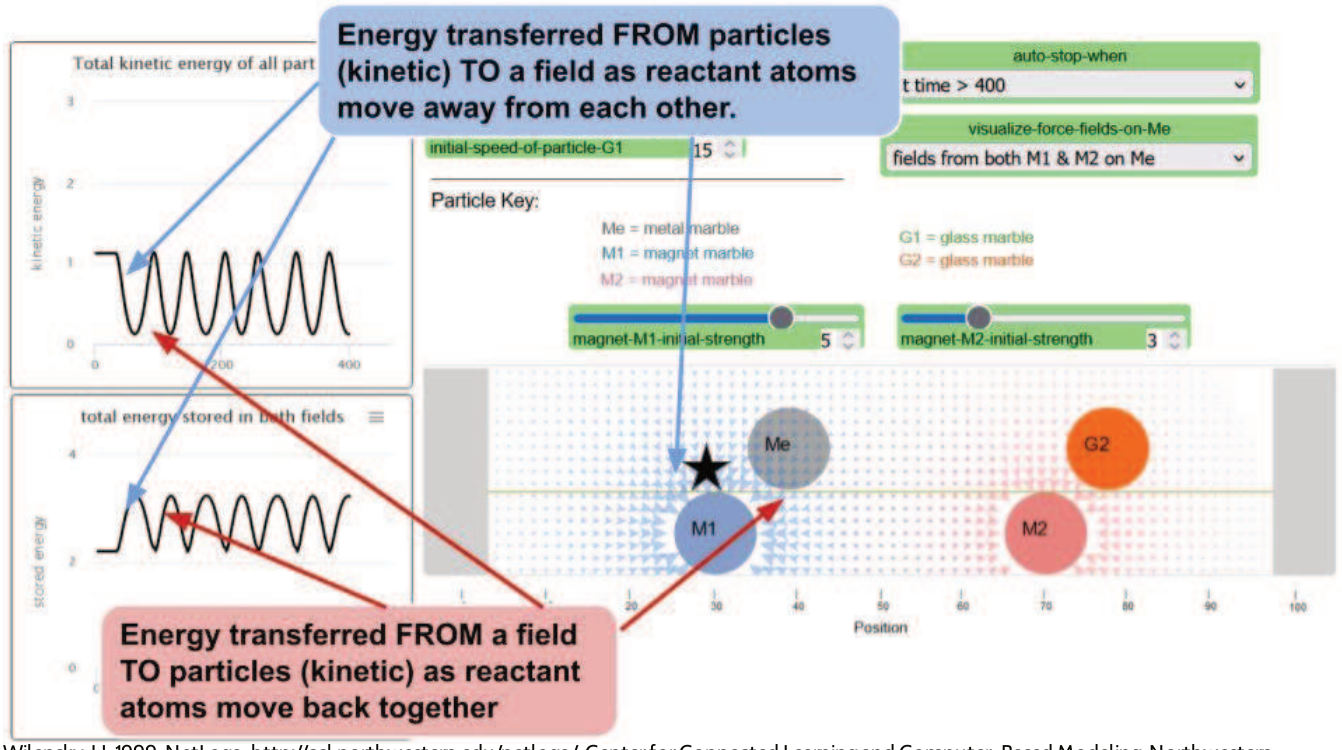
1. Where are the moments that energy is transferred? Mark them with a star (☆) in the screenshot above.

2. Label each star to identify where the energy is transferred FROM and TO.

3. What evidence is there in the model that shows you that energy is conserved?
The combined kinetic energy and energy in the field are about the same before and after the reaction.

4. If this reaction happened in an engine, do you think it would or would not be able to cause the vehicle to move? How do you know? Explain your reasoning in terms of the NET energy transfer into versus out of the system.
The vehicle would move because net energy is transferred to the particles from the field, so they will be able to move faster. The particle in the reaction (*Me*) can even transfer energy to particles not involved in the reaction, like *G2*.

Scenario 3: The bond broken between *Me* and *M1* is stronger than the bond formed between *Me* and *M2*.



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

1. Where are the moments that energy is transferred? Mark them with a star (☆) in the screenshot above.

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The combined kinetic energy and energy in the field are about the same before and after the reaction.

4. If this reaction happened in an engine, do you think it would or would not be able to cause the vehicle to move? How do you know? Explain your reasoning in terms of the NET energy transfer into versus out of the system.
The vehicle would not be able to move because net energy is transferred to the field from the particles, so they will actually be moving slower and will not be able to push on the piston.

Lesson 7: Answer Key

Fuel Energy Released Key

Energy of Bonds Breaking		Energy of Bonds Forming	
Energy to break bonds in fuels: Gasoline (G) = 19,726 kJ 14 (C-C) + 36 (C-H) 14 x 347 kJ + 36 x 413 kJ 19,726 kJ per 2 moles of gasoline Diesel (D) = 29,110 kJ 22 (C-C) + 52 (C-H) 22 x 347 kJ + 52 x 413 kJ 29,110 kJ per 2 moles of diesel	Energy to break bonds in oxygen: G = 12,375 kJ 25 (O=O) 25 x 495 kJ 12,375 kJ per 25 moles of oxygen D = 18,315 kJ 37 (O=O) 37 x 495 kJ 18,315 kJ per 37 moles of oxygen	Energy to form bonds in water: G = 16,812 kJ 36 (O-H) 36 x 467 kJ 16,812 kJ per 18 moles of water D = 24,284 kJ 52 (O-H) 52 x 467 kJ 24,284 kJ per 26 moles of water	Energy to form bonds in carbon dioxide: G = 25,568 kJ 32 (C=O) 32 x 799 kJ 25,568 kJ per 16 moles of carbon dioxide D = 38,352 kJ 48 (C=O) 48 x 799 kJ 38,352 kJ per 24 moles of carbon dioxide
Total energy required to break bonds: G = 32,101 kJ 19,726 kJ + 12,375 kJ D = 47,425 kJ 29,110 kJ + 18,315 kJ		Total energy transferred out of fields when bonds form: G = 42,380 kJ 16,812 kJ + 25,568 kJ D = 62,636 kJ 24,284 kJ + 38,352 kJ	
Net Energy Transfer as a Result of Combustion Reaction			
Net energy transferred into or out of the gasoline and diesel reactions: G = -10,279 kJ (for 2 moles), or about 5,140 kJ/mol transferred out 32,101 k - 42,380 kJ D = -15,211 kJ (for 2 moles), or about 7,606 kJ/mol transferred out 47,425 kJ- 62,636 kJ Students may check their answers against the Fuel Data Cards or **slide L**. They may be surprised to see a discrepancy; if so, remind them that gasoline and diesel do not consist entirely of one type of molecule.			

1. Based on your calculations, would you predict gasoline or diesel to have a greater energy released per mole? Explain your reasoning.

I would predict that diesel has a higher energy released than gasoline. Based on my net energy transfer calculations, 10,279 kilojoules are transferred out of gasoline's fields, while diesel has 15,211 kilojoules transferred out. This shows that diesel combustion transfers more energy out of the fields.

2. We started the lesson by evaluating the claim: "Diesel transfers more energy because you are breaking weaker bonds and forming stronger bonds." Revise that claim using the evidence above to reflect a more supported claim.

The first part of this sentence is correct--diesel has a greater energy released--but the reasoning is incorrect. Gasoline and diesel form and break the same types of bonds (C-C/C-H/O=O are broken; C=O/O-H are formed). What is different is the number of these bonds that are broken and formed. Diesel has more strong bonds forming, so more energy can be released. This difference in the numbers of bonds is why there is a difference in the energy released values.

3. The maximum weight of a semi truck is 80,000 lb. while the average weight of a personal car is 4,289 lb. Explain why gasoline would be a less ideal fuel choice for semi trucks.

Semi trucks have more mass, which means you need more energy to move them. This means you need a fuel with a higher energy released to efficiently move a semi truck. Since gasoline is about 2,500 less kilojoules per mole than diesel, you would need more gasoline to move a semi the same distance as a lesser amount of diesel.

References

Hawley, D. (2021, February 4). *How much does a semi truck weigh?*. J.D. Power. www.jdpower.com/cars/shopping-guides/how-much-does-a-semi-truck-weigh

United States Environmental Protection Agency. (2022, December). *The 2022 EPA automotive trends report: Greenhouse gas emissions, fuel economy, and technology since 1975*. https://www.epa.gov/system/files/documents/2022-12/420s22001.pdf

Zumdahl, S.S., & Zumdahl, S.A. (1999). *Chemistry* (5th ed.). Houghton Mifflin College Division.

Sample Data

	Potassium chloride	Calcium chloride (hydrate)	Calcium chloride (anhydrous)
Mass (g)	5	5	5.1
Volume water (mL)	25	25	25
Initial water temperature (°C)	24.3	23.7	22.7
Temperature immediately after adding salt (°C)	21.9	37.8	26.4
Final temperature (°C)	14.2	45.4	53.4
Change in temperature (°C)	-10.1	21.7	30.7

Lesson 8: Answer Key 1

Calculating Carbon Emissions Key

Directions: Follow the steps to calculate the carbon dioxide (CO_2) emissions for a fuel of your choice. As you work through these calculations, consider how the data and the math can help you think about transportation solutions.

1. CIrcle the fuel for which you will calculate the CO_2 emissions.

	Fuel	Density (g/mL)	Molar mass (g/mol)	Moles per gallon (3785 mL)
a	Gasoline: C_8H_{18}	0.737	114.26	24.4
b	Ethanol: C_2H_6O	0.789	46.08	64.8
c	Diesel: $C_{13}H_{23}$	0.885	179.36	18.7

Students may select any fuel. Note that a different molecule in diesel has been included here than in prior lessons, to provide additional challenge to students who choose that option.

2. Write and balance the chemical equation for the combustion reaction of your chosen fuel with oxygen gas to produce water vapor and carbon dioxide.

$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$
$C_2H_6O + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$
$4\ C_{13}H_{23} + 75\ O_2 \rightarrow 52\ CO_2 + 46\ H_2O$

3. How can you use the balanced equation to determine how many moles of CO_2 are produced when 1 mole of the fuel combusts?

The balanced equation shows how many moles of carbon dioxide are produced when a certain number of moles of fuel combusts. If you know the number of moles of fuel that combusts, you can use that ratio to calculate the amount of carbon dioxide produced.

4. Calculate the mass of CO_2 produced when 1 gallon of the fuel is burned. This will create a conversion factor that you can use in the next step. The molar mass of CO_2 is 44.01 g/mol.

(1 gallon C_8H_{18} / 1) x (24.4 mol C_8H_{18} / 1 gallon) x (16 mol CO_2 / 2 mol C_8H_{18}) x (44.01 g CO_2 / 1 mol CO_2) = 8590 g CO_2 or 8.59 kg CO_2

(1 gallon C_2H_6O / 1) x (64.8 mol C_2H_6O / 1 gallon) x (2 mol CO_2 / 1 mol C_2H_6O) x (44.01 g CO_2 / 1 mol CO_2) = 5704 g CO_2 or 5.70 kg CO_2

(1 gallon $C_{13}H_{23}$ / 1) x (18.7 mol $C_{13}H_{23}$ / 1 gallon) x (52 mol CO_2 / 4 mol $C_{13}H_{23}$) x (44.01 g CO_2 / 1 mol CO_2) = 10,700 g CO_2 or 10.7 kg CO_2

5. Consider three different types of vehicle and their average fuel efficiencies:
   a. car, 24.20 miles per gallon
   b. pickup truck, 17.50 miles per gallon
   c. semi truck, 5.29 miles per gallon

Choose one vehicle and calculate the CO_2 produced when that vehicle drives 100 miles.

Car	
Gasoline	(100 miles / 1) x (1 gallon C_8H_{18} / 24.20 miles) x (8590 g CO_2 / 1 gallon C_8H_{18}) = 35,500 g CO_2 or 35.5 kg CO_2
Ethanol	(100 miles / 1) x (1 gallon C_2H_6O / 24.20 miles) x (5704 g CO_2 / 1 gallon C_2H_6O) = 23,600 g CO_2 or 23.6 kg CO_2
Diesel	(100 miles / 1) x (1 gallon $C_{13}H_{23}$ / 24.20 miles) x (10,700 g CO_2 / 1 gallon $C_{13}H_{23}$) = 44,200 g CO_2 or 44.2 kg CO_2

Pickup truck	
Gasoline	(100 miles / 1) x (1 gallon C_8H_{18} / 17.50 miles) x (8590 g CO_2 / 1 gallon C_8H_{18}) = 49,100 g CO_2 or 49.1 kg CO_2
Ethanol	(100 miles / 1) x (1 gallon C_2H_6O / 17.50 miles) x (5704 g CO_2 / 1 gallon C_2H_6O) = 32,600 g CO_2 or 32.6 kg CO_2
Diesel	(100 miles / 1) x (1 gallon $C_{13}H_{23}$ / 17.50 miles) x (10,700 g CO_2 / 1 gallon $C_{13}H_{23}$) = 61,100 g CO_2 or 61.1 kg CO_2

Semi truck	
Gasoline	(100 miles / 1) x (1 gallon C_8H_{18} / 5.29 miles) x (8590 g CO_2 / 1 gallon C_8H_{18}) = 162,000 g CO_2 or 162 kg CO_2
Ethanol	(100 miles / 1) x (1 gallon C_2H_6O / 5.29 miles) x (5704 g CO_2 / 1 gallon C_2H_6O) = 108,000 g CO_2 or 108 kg CO_2
Diesel	(100 miles / 1) x (1 gallon $C_{13}H_{23}$ / 5.29 miles) x (10,700 g CO_2 / 1 gallon $C_{13}H_{23}$) = 202,000 g CO_2 or 202 kg CO_2

6. Gasoline and diesel contain impurities like sulfur, which react with oxygen in the engine to produce pollutants such as sulfur dioxide (SO_2). Sulfur dioxide reacts with water in the atmosphere to form acid rain, and in high enough concentrations it can also negatively affect respiratory health in people. Gasoline contains an average of 0.0435 moles of sulfur per gallon, and diesel contains 0.104 moles of sulfur per gallon. Ethanol and biodiesel contain 50 to 100 times less sulfur than gasoline and diesel.

Balance the equation for the production of SO_2, then calculate the mass of SO_2 produced when 1 gallon of gasoline or diesel combusts. The molar mass of SO_2 is 64.06 g/mol.

$S_8 + 8\ O_2 \rightarrow 8\ SO_2$

(1 gallon C_8H_{18}/1) x (0.0435 mol S_8 / 1 gallon C_8H_{18}) x (8 mol SO_2 / 1 mol S_8) x (64.06 g SO_2 / 1 mol SO_2) = 22.3 g SO_2

(1 gallon $C_{13}H_{23}$/1) x (0.104 mol S_8 / 1 gallon $C_{13}H_{23}$) x (8 mol SO_2 / 1 mol S_8) x (64.06 g SO_2 / 1 mol SO_2) = 53.3 g SO_2

Lesson 8: Answer Key 2

Cold Pack Key/Rubric

This mid-unit assessment is intended to assess portions of the NGSS dimensions related to the Performance Expectation **HS-PS1-4**: Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)
For information on where specific portions of this Performance Expectation are assessed, see the **NGSS Element Alignment** table below.

This mid-unit assessment is intended to assess the Lesson Level Performance Expectation (LLPE) **8.A**: Develop a model based on evidence to illustrate energy transfer into or out of a chemical reaction system depending on energy transfer into and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)
For information on where specific portions of this Lesson Level Performance Expectation are assessed, see the **NGSS Element Alignment** table below.

While not specifically identified in either HS-PS1-4 or LLPE 8.A, an additional CCC is assessed: CCC: 5.1. This is to provide an opportunity for students to explicitly address energy conservation, as developed in Lessons 6 and 7.

Use the following rubric to assess each student's level of proficiency with each of the **NGSS Elements**. Guidance on how to provide feedback for students based on their overall proficiency and ideas for instruction are also provided.

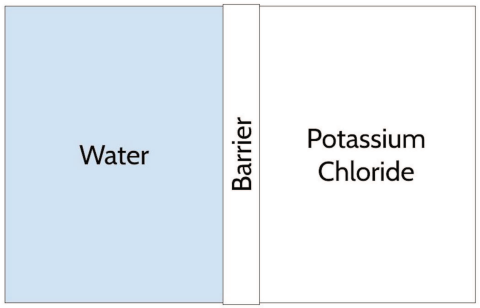
3D Elements	Question #				
	1	2	3	4	5
Developing and Using Models Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (SEP: 2.3)	X			X	X
PS1.A: Structure and Properties of Matter Stable forms of matter are those in which the electric ~~and magnetic~~ field energy is minimized. 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. (HS-PS1-4)			X		
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. (HS-PS1-4)	X	X	X	X	X
Energy and Matter The total amount of energy and matter in closed systems is conserved. (CCC: 5.1)				X	
Energy and Matter Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (CCC: 5.2)		X	X		X

Scoring Guidance. The response elements described below would be considered exemplary at this point in the unit. These are shown in purple text or in purple diagrams below the related question. In some cases different elements of a response are identified with a + symbol. These + elements are not meant to be all inclusive, but are suggestions for different ideas your students might include.

The following scoring guidance can help you identify different elements that students should (or could) include in their responses.

- If several of the elements marked with a + are missing from a student's response, this may indicate that the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the elements marked with a + are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.
- If the elements marked with a ++ are present in a student's response, this indicates that the student is bringing a deeper understanding of the science ideas or a deeper engagement with the practice to their response. Students should not be penalized if ideas marked with a ++ are not present in their response.

Question 1: The cold pack is activated by breaking the barrier between two substances (see image), usually by hitting or squeezing the cold pack. Then the two substances can mix and a chemical process occurs.

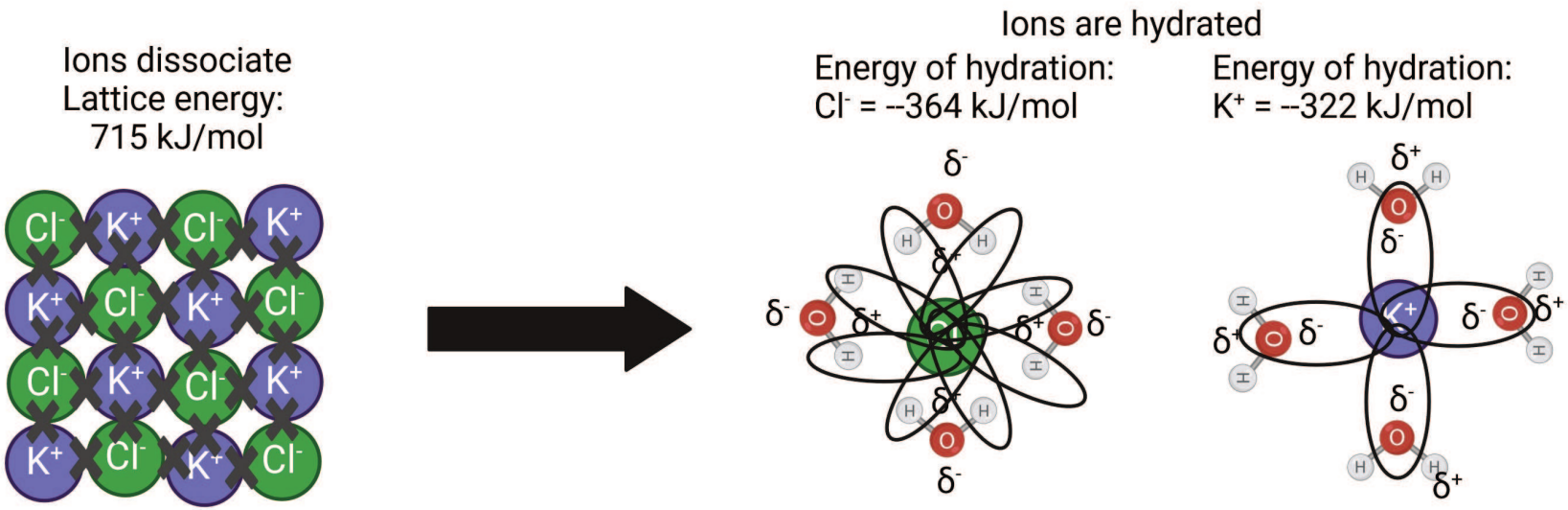


See the chemical equation for the interaction between potassium chloride and water below. Show which bonds are being broken and which ones are being formed by marking directly on the formula using the key provided. You do not need to perform any calculations with energy.

KEY
O (circle) = bonds formed
X (cross out) = bonds broken

Be sure to:

- account for bonds or other intermolecular forces broken and formed in all substances in the process.



Illustrations created by OpenSciEd in Biorender

+ at least one K^+-Cl^- bond being broken in the reactants
+ at least one K^+-H_2O attraction being formed in the products
+ at least one Cl^--H_2O attraction being formed in the products

Question 2: The chemical process that occurs between potassium chloride and water causes the temperature to change. Add data from your Cold Pack Investigation to the following table.
Data will vary.

Based on your data, is this a process where net energy is being transferred into or out of the system, and why? Answers will vary based on the measurements students made.

This is a process where net energy is being transferred **into the system / out of the system (circle one)** because...
+ Circled "into the system".
+ A temperature decrease was detected.
+ A temperature decrease indicates more energy is being transferred from the surroundings and into the fields between particles to break bonds than out of the fields in the system.

Question 3: After you break the barrier to activate the cold pack, the instructions say to knead it to mix the contents. What does kneading the cold pack do to the kinetic energy of the particles in the system? Where does that energy go?

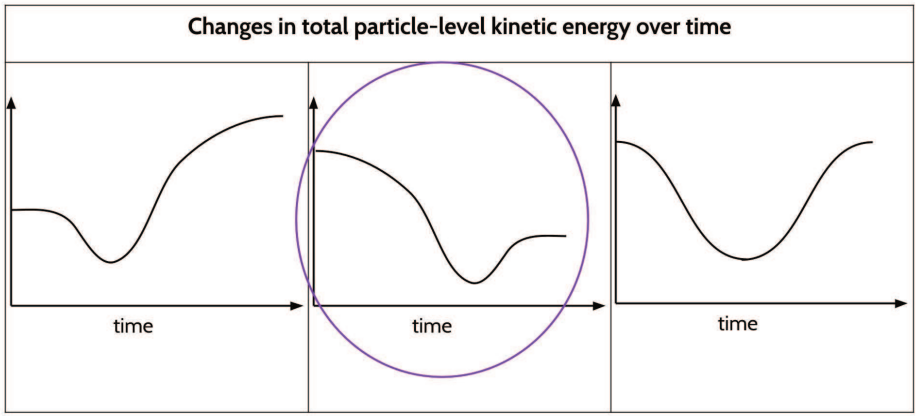
+ Shaking the cold pack inputs energy into the system.

+ This increases the kinetic energy (KE) of the particles in the system because they will have more movement if you shake them.
+ The energy goes into the fields between particles to break the bonds between the particles of the reactants.

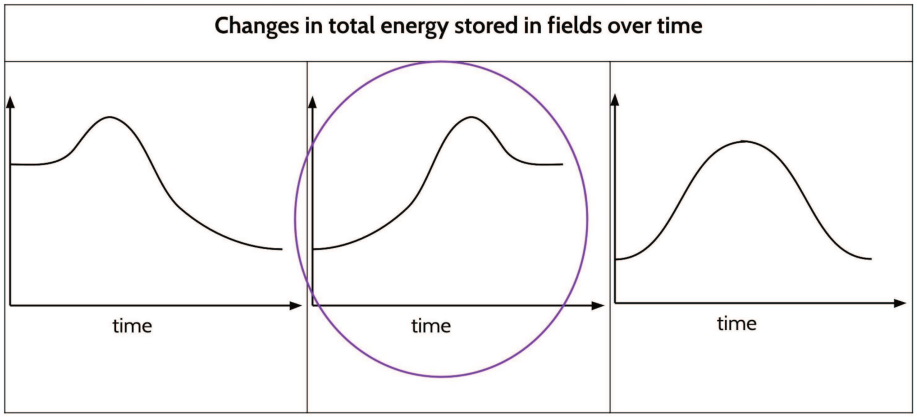


Additional accurate element not essential to this item:
++ Then, when the particles come together, some of the energy from the fields is transferred back into the kinetic energy of the particles as they speed up a bit.

Question 4a: Imagine that we performed this process in a simulation like the ones we have used in this unit. Circle the graph that best fits the **changes in kinetic energy** over time for this process.



Question 4b: Imagine that we performed this process in a simulation like the ones we have used in this unit. Circle the graph that best fits the **changes in energy stored in fields** over time for this process.



Question 4c: Explain how the graphs you selected in 4a and 4b show that **energy is conserved** in the process you observed, even though there is a temperature change. Use evidence from classroom investigations to support your answer.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	+ A decrease in temperature means particles are moving less and have less kinetic energy. + Energy is always conserved in reactions. + References to classroom evidence are provided, but no particular evidence is cited.	+ A decrease in temperature means particles are moving less and have less kinetic energy. + The energy at any given time should add up to a constant amount. + Energy transfers between the motion of particles (kinetic energy) and the field. + Evidence is provided but not strongly connected to the explanation.	+ A decrease in temperature means particles are moving less and have less kinetic energy. + The energy at any given time should add up to a constant amount. + The seemingly "missing" energy from a temperature decrease is actually stored within the fields of the products. + Energy in the field is relatively high at the beginning of the process, increases as kinetic energy is transferred in, and then is transferred to kinetic energy as particles speed toward each other to form new bonds. + Evidence from classroom investigations is provided demonstrating that we know that energy is transferred into the fields between particles when bonds are broken. <u>Additional accurate element not essential to this item:</u> ++ Multiple lines of evidence are brought into the argument from prior investigations.

Example	The process gets colder because there is less kinetic energy, but energy is always conserved in reactions. We investigated this and saw that the total amount of energy stays the same.	I know that energy is conserved because the energy from the two graphs looks like it always adds up to about the same amount. We investigated this and saw that kinetic energy is lowest at the end of the process because energy is transferred into the field. Less particle kinetic energy means that the temperature goes down.	I know that energy is conserved because the kinetic energy of the particles and the energy stored in electric fields seem to add up to a constant number throughout the process. Although I did not measure it in this instance, we observed in the breaking and forming bonds investigation that when kinetic energy is input to break the bond, energy is transferred into the electric field between particles. They get farther apart and new bonds start to form, which means energy is transferred back to the particles as kinetic energy. It looks like energy is lost when the temperature decreases, but it is actually just transferred into the electric fields between particles.
Feedback / What to Do	*To revise toward Linking:* • Suggest explicit discussion of energy conservation. • Suggest direct comparison of kinetic energy and energy in the field at different points in the process.. • Suggest inclusion of evidence.	*To revise toward Organizing:* • Suggest tying back to temperature. • Suggest reflection on why it looks like energy is not conserved. • Suggest specific discussion of how evidence explains energy conservation.	*To revise toward Extending:* • Invite students to quantify their thinking using publicly available bond energy data.

Question 5: Use the graphs you identified in 4a and 4b as a model to explain how energy transfers caused the temperature change you observed. Focus on the reactant (potassium chloride) and final products (potassium and chloride ions). You may use words and/or drawings in your response.

$KCl_{(s)} \rightarrow K^{+}_{(aq)} + Cl^{-}_{(aq)}$

Be sure to include:

- relevant particles and electric fields between particles.
- transfers of energy between components as well as any transfers into or out of the system.
- relative changes in **kinetic energies** of the reactants and products.
- relative changes in **energy stored in fields.**
- connection between energy and temperature.
- evidence from classroom investigations to support your answer.

	Foundational Pieces	Linked Understanding	Organized Understanding

3D Elements	+ In this process more energy goes into the system than is transferred out of it. + The products have less kinetic energy than the reactants. + The products are colder than the reactants. + References to classroom evidence are provided, but no particular evidence is cited.	+ In this process more energy goes into the system than is transferred out of it. + It takes energy to break a bond in the reactants. + Energy is transferred out of the system (released) when bonds are formed in the products. + The products are colder than the reactants because they have less kinetic energy. + Evidence is provided but not strongly connected to the explanation.	+ In this process more energy goes into the system than is transferred out of it. + It takes energy to break a bond in the reactants as energy is transferred into the field. + Energy is transferred out of the system (released) when bonds are formed in the products. + The net change of energy is determined by how many and how strong the bonds are that have broken and formed. + The products are colder than the reactants because they have less kinetic energy, with the remainder having been transferred into the fields between particles. + Evidence from classroom investigations is provided demonstrating that we know that energy is transferred into the fields between particles when bonds are broken, and transferred from the fields to particles when bonds are formed. <u>Additional accurate elements not essential to this item:</u> ++ Here, the bonds that form must be weaker than the bonds that break or there are fewer of them, so not as much energy was released as was used to break the bonds. ++ Energy goes into the fields as the particles are pushed or pulled apart, so they have less kinetic energy. When new bonds form, particles speed up and come together, releasing some energy from the field.

Example	More energy transferred into the system than went out of it, meaning it is colder at the end and there is less kinetic energy. We saw this in an investigation with simulated marbles.	More energy was put into this process than was transferred out of it. It took energy to break the bonds in the reactants, but then when new bonds formed, some energy was released. Less energy came out of the fields when new bonds formed, so there was less kinetic energy at the end. We did an investigation with simulated marbles and saw that kinetic energy can go down in the process because of the energy it took to break those reactant bonds.	This temperature decrease occurred because there was a net change in energy, with less energy released when product bonds formed than when reactant ones broke, because the bonds formed must have been weaker than the ones that were broken. Energy had to be transferred to the reactants to break the bonds in the ionic compound. This energy was transferred to the fields between particles. Then new bonds formed, and less energy transferred to the particles as they moved (kinetic energy). This energy was eventually transferred out of the system as particles collided, meaning that the temperature after the process was lower than the temperature before the process. We saw this in the breaking and forming bonds investigation. When we made the reactant bonds stronger than the product bonds, more energy was put in to break the bonds than was released after new bonds formed.
Feedback / What to Do	*To revise toward Linking:* • Suggest adding ideas about how energy plays a role in breaking and forming bonds. • Suggest adding specific evidence.	*To revise toward Organizing:* • Suggest consideration of how energy is transferring into and out of fields in the process. • Suggest explicit consideration of net energy transfer. • Suggest adding additional evidence.	*To revise toward Extending:* • Invite students to quantify their thinking using publicly available bond energy data. • Suggest that students discuss bond strengths explicitly.

Foundational Understanding	Linked Understanding	Organized Understanding

	• Review results from the simulation investigations in Lesson 6. • Review questions on the Driving Question Board related to energy flows in chemical processes. • Invite students to think about how specific components from the unit can be represented and connected in models, and what evidence they have for these relationships (i.e., reactants, products, bonds, kinetic energy, energy in fields, bond energies, net energy transfer, bonds breaking and forming). • Review evidence of energy conservation from the simulations.	• Review the assessment with students to foster students' making connections between features of their models and evidence in explanations. • Invite students to think about energy transfer in chemical processes and how they can represent these ideas in models or support them with evidence. • Ask students to reflect on how simulations in the unit show energy conservation, and why energy appears not to be conserved at the macroscopic level.	• Invite students to connect and extend their understanding to predict the net flow of energy of reactants with more or less bond stability. • Encourage students to think about alternate energy flows when the amount of substances in the process is varied.

Lesson 8: Answer Key 3

Hot Pack Key/Rubric

This mid-unit assessment is intended to assess portions of the NGSS dimensions related to the Performance Expectation **HS-PS1-4**: Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)
For information on where specific portions of this Performance Expectation are assessed, see the **NGSS Element Alignment** table below.

This mid-unit assessment is intended to assess the Lesson Level Performance Expectation (LLPE) **8.A**: Develop a model based on evidence to illustrate energy transfer into or out of a chemical reaction system depending on energy transfer into and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)
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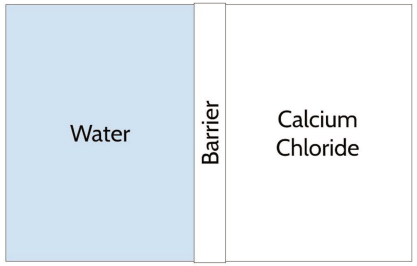
3D Elements	Question #				
	1	2	3	4	5
Developing and Using Models Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (SEP: 2.3)	X			X	X
PS1.A: Structure and Properties of Matter Stable forms of matter are those in which the electric ~~and magnetic~~ field energy is minimized. 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. (HS-PS1-4)			X		
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. (HS-PS1-4)	X	X	X	X	X
Energy and Matter The total amount of energy and matter in closed systems is conserved. (CCC: 5.1)				X	
Energy and Matter Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (CCC: 5.2)		X	X		X

Scoring Guidance. The response elements described below would be considered exemplary at this point in the unit. These are shown in purple text or in purple diagrams below the related question. In some cases different elements of a response are identified with a + symbol. These + elements are not meant to be all inclusive, but are suggestions for different ideas your students might include.

The following scoring guidance can help you identify different elements that students should (or could) include in their responses.

- If several of the elements marked with a + are missing from a student's response, this may indicate that the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the elements marked with a + are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.
- If the elements marked with a ++ are present in a student's response, this indicates that the student is bringing a deeper understanding of the science ideas or a deeper engagement with the practice to their response. Students should not be penalized if ideas marked with a ++ are not present in their response.

Question 1: The hot pack is activated by breaking the barrier between two substances (see image), usually by hitting or squeezing the hot pack. Then the two substances can mix and a chemical process occurs.

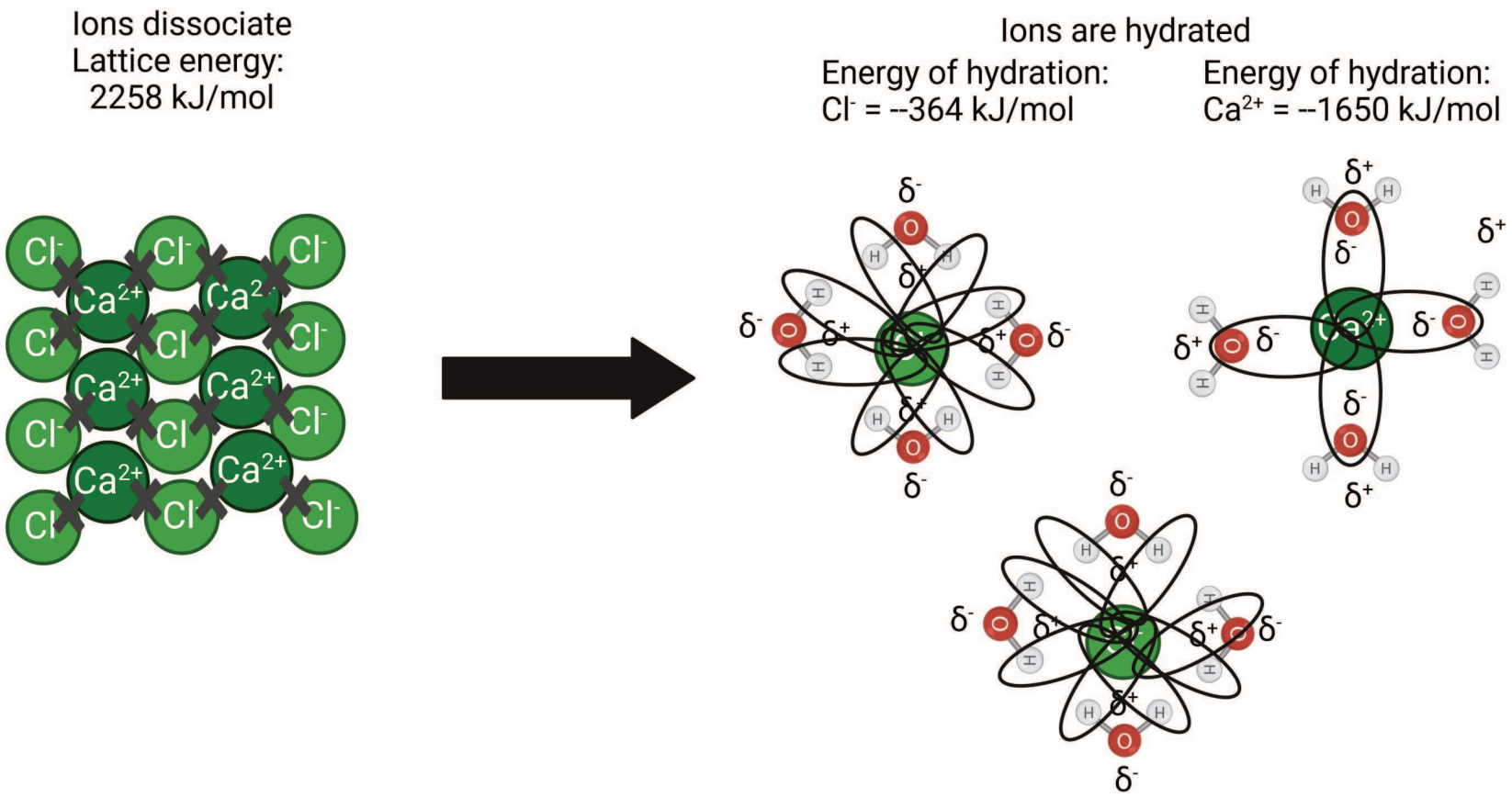


See the chemical equation for the interaction between calcium chloride and water below. Show which bonds are being broken and which ones are being formed by marking directly on the formula using the key provided. You do not need to perform any calculations with energy.

KEY
O (circle) = bonds formed
X (cross out) = bonds broken

Be sure to:

- account for bonds or other intermolecular forces broken and formed in all substances in the process.



Illustrations created by OpenSciEd in Biorender

+ at least one Ca^{2+}-Cl^{-} bond being broken in the reactants
+ at least one Ca^{2+}-H_2O attraction being formed in the products
+ at least one Cl^{-}-H_2O attraction being formed in the products

Question 2: The chemical process that occurs between calcium chloride and water causes the temperature to change. Add data from your Hot Pack Investigation to the following table.
Data will vary.

Based on your data, is this a process where net energy is being transferred into or out of the system, and why? Answers will vary based on the measurements students made.

This is a process where net energy is being transferred **into the system / out of the system (circle one)** because...
+ Circled "out of the system".
+ A temperature increase was detected.
+ A temperature increase indicates more energy is being transferred out of the fields between particles and into the particles and surroundings than from the surroundings and into the fields between particles to break bonds in the system.

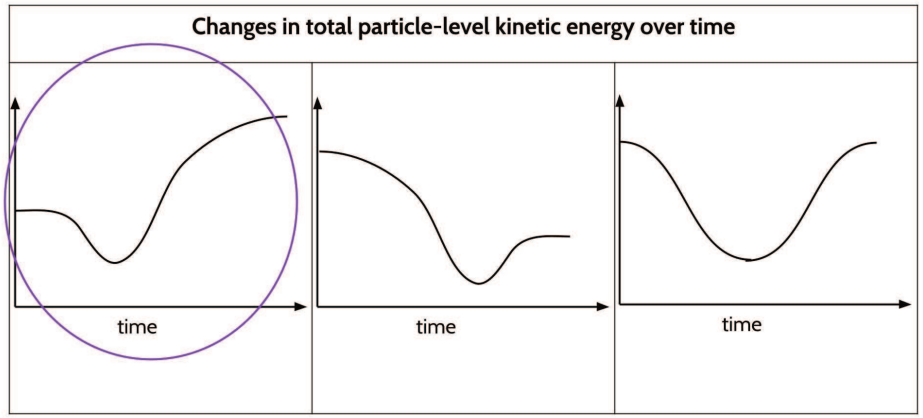
Question 3: After you break the barrier to activate the hot pack, the instructions say to knead it to mix the contents. What does kneading the hot pack do to the kinetic energy of the particles in the system? Where does that energy go?



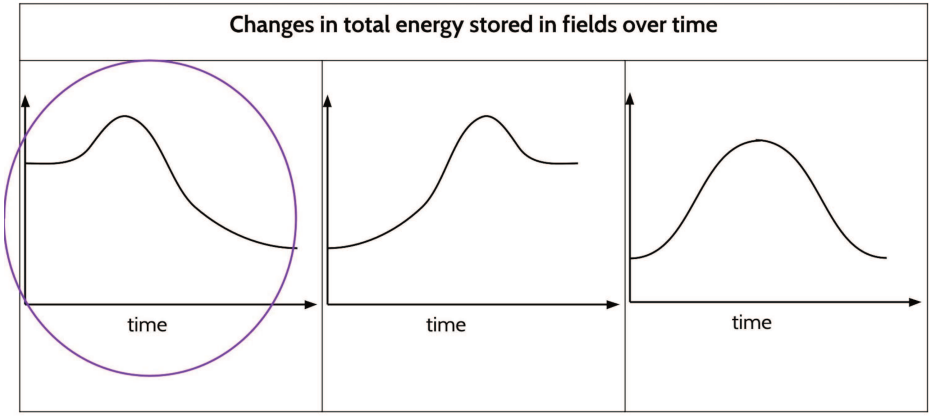
+ Shaking the hot pack inputs energy into the system.
+ This increases the kinetic energy (KE) of the particles in the system because they will have more movement if you shake them.
+ The energy goes into the fields between particles to break the bonds between the particles of the reactants.

Additional accurate element not essential to this item:
++ Then, when the particles come together, some of the energy from the fields is transferred back into the kinetic energy of the particles as they speed up a bit.

Question 4a: Imagine that we performed this process in a simulation like the ones we have used in this unit. Circle the graph that best fits the **changes in kinetic energy** over time for this process.



Question 4b: Imagine that we performed this process in a simulation like the ones we have used in this unit. Circle the graph that best fits the **changes in energy stored in fields** over time for this process.



Question 4c: Explain how the graphs you selected in 4a and 4b show that **energy is conserved** in the process you observed, even though there is a temperature change. Use evidence from classroom investigations to support your answer.

	Foundational Pieces	Linked Understanding	Organized Understanding

3D Elements	+ An increase in temperature means particles are moving more and have more kinetic energy. + Energy is always conserved in reactions. + References to classroom evidence are provided, but no particular evidence is cited.	+ An increase in temperature means particles are moving more and have more kinetic energy. + The energy at any given time should add up to a constant amount. + Energy transfers between the motion of particles (kinetic energy) and the field. + Evidence is provided but not strongly connected to the explanation.	+ An increase in temperature means particles are moving more and have more kinetic energy. + The energy at any given time should add up to a constant amount. + The seemingly "created" energy from a temperature increase is actually released from the fields of the products. + Energy in the field is relatively high at the beginning of the process, increases as kinetic energy is transferred in, and then is transferred to kinetic energy as particles speed toward each other to form new bonds. + Evidence from classroom investigations is provided demonstrating that we know that energy is transferred into the fields between particles when bonds are broken. <u>Additional accurate element not essential to this item:</u> ++ Multiple lines of evidence are brought into the argument from prior investigations.
Example	The process gets hotter because there is more kinetic energy, but energy is always conserved in reactions. We investigated this and saw that the total amount of energy stays the same.	I know that energy is conserved because the energy from the two graphs looks like it always adds up to about the same amount. We investigated this and saw that kinetic energy is highest at the end of the process because energy is transferred out of the field. More particle kinetic energy means that the temperature goes up.	I know that energy is conserved because the kinetic energy of the particles and the energy stored in electric fields seem to add up to a constant number throughout the process. Although I did not measure it in this instance, we observed in the breaking and forming bonds investigation that when kinetic energy is input to break the bond, energy is transferred into the electric field between particles. They get farther apart and new bonds start to form, which means energy is transferred back to the particles as kinetic energy. It looks like energy is created when the temperature increases, but it is actually just released from the electric fields between particles.

Feedback / What to Do	*To revise toward Linking:* • Suggest explicit discussion of energy conservation. • Suggest a direct comparison of kinetic energy and energy in the field at different points in the process. • Suggest inclusion of evidence.	*To revise toward Organizing:* • Suggest tying back to temperature. • Suggest reflection on why it looks like energy is not conserved. • Suggest a specific discussion of how evidence explains energy conservation.	*To revise toward Extending:* • Invite students to quantify their thinking using publicly available bond energy data.

Question 5: Use the graphs you identified in 4a and 4b as a model to explain how energy transfers caused the temperature change you observed. Focus on the reactant (calcium chloride) and final products (calcium and chloride ions). You may use words and/or drawings in your response.

$CaCl_{2(s)} \rightarrow Ca^{2+}_{(aq)} + 2Cl^{-}_{(aq)}$

Be sure to include:

- relevant particles and electric fields between particles.
- transfers of energy between components as well as any transfers into or out of the system.
- relative changes in **kinetic energies** of the reactants and products.
- relative changes in **energy stored in fields.**
- connection between energy and temperature.
- evidence from classroom investigations to support your answer.

	Foundational Pieces	Linked Understanding	Organized Understanding

3D Elements	+ In this process more energy is transferred out of the system than goes into it. + The products have more kinetic energy than the reactants. + The products are hotter than the reactants. + References to classroom evidence are provided, but no particular evidence is cited.	+ In this process more energy is transferred out of the system than goes into it. + It takes energy to break a bond in the reactants. + Energy is transferred out of the system (released) when bonds are formed in the products. + The products are hotter than the reactants because they have more kinetic energy. This energy was transferred from the electric field between particles. + Evidence is provided but not strongly connected to the explanation.	+ In this process more energy is transferred out of the system than goes into it. + It takes energy to break a bond in the reactants as energy is transferred into the field. + Energy is transferred out of the system (released) when bonds are formed in the products. + The net change of energy is determined by how many and how strong the bonds are that have broken and formed. + The products are hotter than the reactants because they have more kinetic energy. This energy was transferred from the electric field between particles. + Evidence from classroom investigations is provided demonstrating that we know that energy is transferred into the fields between particles when bonds are broken, and transferred from the fields to particles when bonds are formed. <u>Additional accurate elements not essential to this item:</u> ++ Here, the bonds that form must be stronger than the bonds that break or there are more of them, so more energy was released than was used to break the bonds. ++ Energy goes into the fields as the particles are pushed or pulled apart, so they have less kinetic energy. When new bonds form, particles speed up and come together, releasing some energy from the field.

Example	More energy transferred out of the system than went into it, meaning it is hotter at the end and there is more kinetic energy. We saw this in an investigation with simulated marbles.	More energy transferred out of this process than was put into it. It did take energy to break the bonds in the reactants, but then when new bonds formed, energy was released. Since these particles were moving, they had lots of kinetic energy and therefore a higher temperature. This energy came out of the field between the particles. We did an investigation with simulated marbles and saw that kinetic energy can go up in the process because of the new bonds forming.	This temperature increase occurred because there was a net change in energy, with less energy transferred into fields when reactant bonds broke than was released when product bonds formed, because the bonds that were broken must have been weaker than the ones that were formed. Energy had to be transferred to the reactants to break the bonds in the ionic compound. This energy was transferred to the fields between particles. Then new bonds formed, but more energy transferred to the particles as they moved (kinetic energy). This means there was an overall net transfer of energy to the particles, meaning that the temperature after the process was higher than the temperature before the process. We saw this in the breaking and forming bonds investigation. When we made the reactant bonds weaker than the product bonds, more kinetic energy resulted than we put in to break the bonds.
Feedback / What to Do	*To revise toward Linking:* • Suggest adding ideas about how energy plays a role in breaking and forming bonds. • Suggest adding specific evidence.	*To revise toward Organizing:* • Suggest consideration of how energy is transferring into and out of fields in the process. • Suggest explicit consideration of net energy transfer. • Suggest adding additional evidence.	*To revise toward Extending:* • Invite students to quantify their thinking using publicly available bond energy data. • Suggest that students discuss bond strengths explicitly.

Foundational Understanding	Linked Understanding	Organized Understanding

	• Review results from the simulation investigations in Lesson 6. • Review questions on the Driving Question Board related to energy flows in chemical processes. • Invite students to think about how specific components from the unit can be represented and connected in models, and what evidence they have for these relationships (i.e., reactants, products, bonds, kinetic energy, energy in fields, bond energies, net energy transfer, bonds breaking and forming). • Review evidence of energy conservation from the simulations.	• Review the assessment with students to foster students' making connections between features of their models and evidence in explanations. • Invite students to think about energy transfer in chemical processes and how they can represent these ideas in models or support them with evidence. • Ask students to reflect on how simulations in the unit show energy conservation, and why energy appears not to be conserved at the macroscopic level.	• Invite students to connect and extend their understanding to predict the net flow of energy of reactants with more or less bond stability. • Encourage students to think about alternate energy flows when the amount of substances in the process is varied.

Lesson 9 Teacher Reference

Voltmeter Build Directions

Follow these general safety procedures:

- Wear sanitized safety glasses with side shields or indirectly vented chemical splash goggles during the setup, hands-on, and takedown segments of this activity.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Use caution when working with a hot glue gun! Can burn skin on direct contact.
- Use caution when working with sharps like wires which can cut or puncture skin.
- Follow procedures set up for disposal of materials.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.

Modifying the ammeter to function as a voltmeter

The directions on this page outline the modification of the ammeters students used in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* so that each one can also serve as a voltmeter. The construction of the ammeters was outlined in Lesson 13 of that unit, in *Ammeter Construction Directions*. Repeat the directions below to modify all seven ammeters.

Materials needed for each base ammeter (see *Ammeter Construction Directions* for instructions if not already built):

- LED Voltmeter Ammeter (Red and Blue Digital Multimeter Display Voltage Current Tester, DC 0-100V 10A)
- 9V battery
- 9V battery connector
- 2-pin boat rocker switch
- 8-oz round deli container with lid

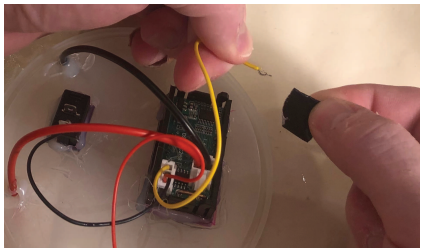
Additional materials needed to change each ammeter to a voltmeter:

- 1.5V battery
- Yellow wire with alligator clips
- Black wire with alligator clips

Materials needed for assembly:

- Electrical tape
- Hot glue gun
- Hand drill

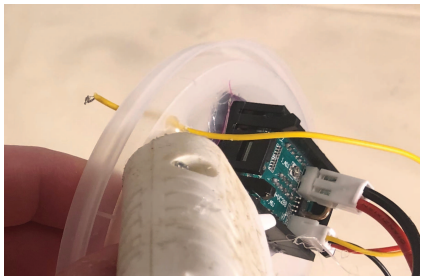
Remove the lid of the deli container from the ammeter to expose the underlying wires. Locate the yellow wire with electrical tape wrapped around its end. This wire is for measuring voltage. Remove the electrical tape from the end of the wire.



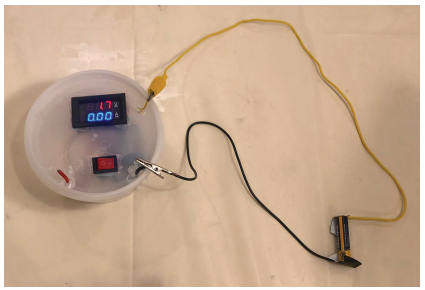
Use a hand drill (or the end of a pen) to make one new hole in the lid at the top-right side of the display panel. Thread the yellow wire through this hole so that about ½" to 1" of the wire sticks through the lid. Hot glue the opening where the yellow wire meets the front of the lid.



Hot glue the opening where the yellow wire meets the back of the lid.



Secure the lid to the container. Turn the switch on to test that the ammeter panel still works. Test the new voltage measurement capabilities by taping wires with alligator clips to the ends of a 1.5V battery. Tape the other end of each wire with alligator clips to the yellow wire and the black wire, respectively. The directionality of the wires matters for this. The black wire should connect to the negative end of the battery and the yellow wire should connect to the positive end.

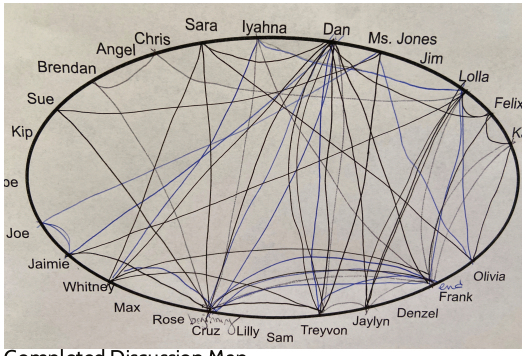


Lesson 9 Teacher Reference

Discussion Mapping Tool

Instructions

1. Print one copy of the second page of this tool for each class section.
2. Add students' names to the circle in the order that students are sitting. You may want to do this ahead of time and then ask students to sit according to the map. The image shows an example:
3. Write the question that students are trying to answer at the top of the page.
4. Select a student recorder who will map the discussion as it happens. Decide ahead of time if you will have multiple students take turns mapping, and when you will move the map to a new student recorder.
5. If this is the first time you are using a discussion map, explain to students that each time someone speaks, the recorder will draw a line from the previous speaker to the new speaker's name. You may want to mark where the conversation begins and ends, but the goal is to map the overall conversation patterns rather than to be able to retrace the entire conversation.
6. Once the discussion begins, allow students to take the lead on moving the discussion forward. Sit in the circle as a participant rather than standing in front of the class as a facilitator. This will allow students to practice building on each other's ideas directly.
7. Be mindful of group dynamics, especially when displaying the map and discussing patterns of contributions. Avoid focusing on the contributions of single students and instead redirect the class to notice class-level patterns.



Completed Discussion Map

Discussion Mapping Codes

The key at the bottom of the discussion map contains codes that can be used to label the types of student contributions. The first few times that you create a discussion map with your students, you should focus only on recording the flow of the conversation. This allows students to get comfortable with the process. Once students have experience recording and interpreting those initial patterns, you can add discussion mapping codes to future discussion maps. Start by adding "low risk" or more accessible codes first such as claim given, evidence added, agreed, or disagreed. There is an extra column where you can add your own discussion codes as needed based on individual class needs and agreements. You may also choose to use just some of the discussion codes, based on the type of discussion that your students are having. In this case, be sure to cross out the codes that you are not using so that student recorders know not to include them.

Key Ideas

There is space to list up to three key ideas that emerge from the discussion on the tool itself so that the class can keep track of the ideas that are raised in the discussion. If you choose to use codes to annotate student contributions, you can also use the codes "1", "2", and "3" to map when those ideas are talked about.

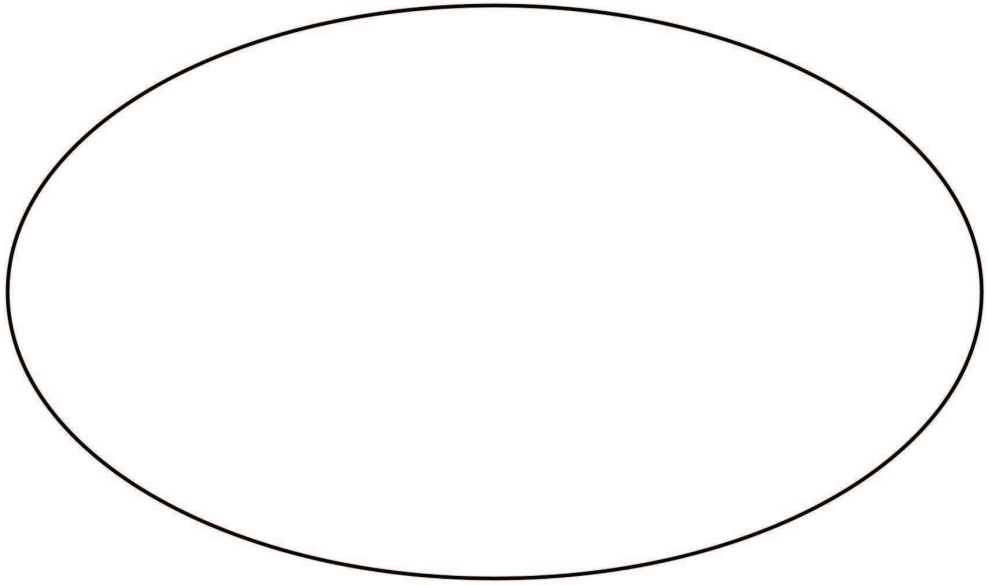
Adaptations

- For a large class, map discussions using a fishbowl structure. Arrange students in an inner and an outer circle. Have the inner circle discuss the question while the students in the outer circle map the discussion.
- Consider having sentence frames displayed on a slide or poster to support multilingual learners.

Question we are trying to answer:

Date:_____
L#: _____
Period: ___

Key Ideas



Discussion Codes (Choose up to 3)				
C- claim given	**CL**- clarified idea	**?**- asked question	**T**- tied ideas together	**I**- interrupted
E- gave evidence	**A**- affirmed/agreed	**NI**- new idea added	**RP**- related phenomena	
OT- off topic	**D**- disagreed	**R**- repeated idea	-- idea ended	

Lesson 9 Teacher Reference

Electrode Station Setup

Setting up the different battery stations

Materials needed for stations:

- 7 clear beakers or plastic cups
- Aluminum foil
- Copper foil
- 2 zinc electrodes (approximately 4" x 0.75" strips)
- 2 iron electrodes (approximately 4" x 0.75" strips)
- 14 plastic clothespins or binder clips
- 7 voltmeters (see *Voltmeter Build Directions*)

Materials needed for stock solution:

- 3 L water
- 60 g table salt (sodium chloride)
- 45 mL vinegar
- 1 gallon jug

Additional materials:

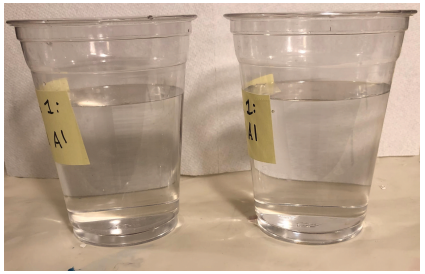
- Soap and water to wash iron electrodes
- Towel or paper towel
- Permanent marker
- Scissors

Prepare the electrodes. Clean the iron (Fe) samples with soap and water and dry them. They have a protective oil layer to prevent oxidation that will also prevent them from interacting with the other electrodes unless this layer is removed.

Label seven containers (beakers or clear plastic cups) for the different stations to designate the combination of metallic electrodes you will eventually place in each. The combinations will involve at least one of the following metals: Aluminum (Al), Copper (Cu), Zinc (Zn), and Iron (Fe). These labels should list the anode before the cathode, as shown:

• Station 1: Al and Al • Station 2: Al and Zn • Station 3: Al and Fe	• Station 4: Al and Cu • Station 5: Cu and Cu	• Station 6: Zn and Cu • Station 7: Fe and Cu

Mix a stock electrolyte solution of table salt, vinegar, and water using the following proportions: 3 L distilled water 60 g table salt (sodium chloride) 45 mL vinegar Pour equal amounts of the stock solution into the 7 cups/beakers so that each container is about ¾ full.



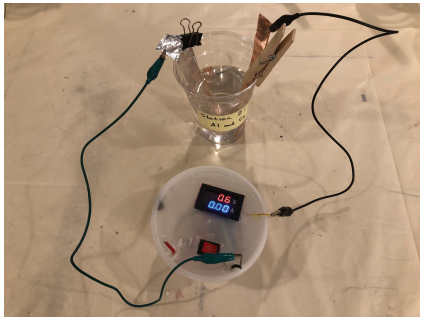
Cut five 4” x 6” rectangles of aluminum foil and five 4” x 6” rectangles of copper foil. Fold each piece of foil in half over the 4” length. Do this two more times until each piece of foil is a 1/2” x 6” strip.



These strips of aluminum and copper foil will be paired up with each other or with another metal to make the electrode pairs indicated by the labels on the containers. Each strip of metal will now be referred to as an electrode: either the anode (which will give electrons) or the cathode (which will receive the electrons). Use a permanent marker to label each electrode with its corresponding element symbol. Attach each electrode to the inside of the corresponding container using a plastic clothespin or binder clip. The bottom half (or more) of each electrode should be in the electrolyte solution and the top should be sticking out of the container. The bottoms of the electrode pairs should not be touching each other.



For each container, attach one end of an alligator clip to each electrode. Before students use the equipment, identify the anode and cathode, and test the voltage of each battery: Attach the other end of the anode (-) alligator clip, or the one attached to the first metal listed on the container, to the black wire on the voltmeter. Attach the other end of the cathode (+) alligator clip, or the one attached to the second metal listed, to the yellow wire on the voltmeter. The directionality of the wires matters for this step. If you get a reading of 0.0V, switch the alligator clips attached to the yellow and the black wires to see if you get a reading above this value. Once you have a non-zero voltage reading, use the permanent marker to label the electrode attached to the black wire as the “anode” and the electrode attached to the yellow wire as the “cathode.”



Each container is now ready to serve as a wet cell battery. Place each battery at the corresponding station location you designate for the student investigation.

Repeat the test of the voltage for each battery. You should get voltage readings close to the values shown (+/- 0.1V):

• Station 1: Al and Al = 0.0V • Station 2: Al and Zn = 0.4V • Station 3: Al and Fe = 0.3V	• Station 4: Al and Cu = 0.6V • Station 5: Cu and Cu = 0.0V	• Station 6: Cu and Zn = 0.9V • Station 7: Cu and Fe = 0.5V

Lesson 9: Answer Key

Battery Design Key

9.B Use evidence from student investigations and research to propose a battery design that results in the largest energy output based on the types of solutions and metals used in the battery and the matter and force interactions between them. (SEP: 6.5; DCI: PS3.A.4; CCC: 2.2)

3D Elements Addressed in This Assessment
Constructing Explanations and Designing Solutions. Design, ~~evaluate, and/or refine~~ a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, ~~prioritized criteria, and trade-off considerations~~. (SEP: 6.5)
Definitions of Energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). ~~This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.~~ (PS3.A.4)
Cause and Effect. 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. (CCC: 2.2)

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	In this design argument look for: Students' claims address the design problem of building a battery that allows for a high energy output rate. Students support their claims with minimal evidence from the lesson or surface-level scientific knowledge that explains the evidence they observed. Students' arguments use microscale phenomena like particle motion to suggest cause-and-effect relationships for observed energy transfers.	In this design argument look for: Students' claims address the design problem of building a battery that allows for a high energy output rate. Students support their claims with some evidence from the lesson and surface-level scientific knowledge that explains the evidence they observed. Students' arguments use microscale phenomena like particle motion to suggest accurate cause-and-effect relationships for observed energy transfers.	In this design argument look for: Students' claims address the design problem of building a battery that allows for a high energy output rate. Students support their claims with specific evidence from the lesson and scientific knowledge that explains the evidence they observed. Students' arguments use microscale phenomena like electronegativity and solution concentration to suggest accurate cause-and-effect relationships for observed energy transfers using the movement of particles.

Example	*The highest rate of energy output would occur with copper and zinc electrodes and a calcium chloride solution.* *I selected these electrodes and solution because they conducted electricity well in our investigation.* *These electrodes were able to pull electrons from one to another better than the other electrodes were, so they conduct electricity well.*	*The highest rate of energy output would occur with copper and zinc electrodes and a calcium chloride solution.* *I selected these electrodes and solution because we saw in our investigation that the voltage was highest with the copper and zinc electrodes, while the current was highest with the calcium chloride solution. A high voltage and current are important because they combine to make a high rate of energy transfer.* *The electrodes have a high voltage because copper pulls electrons toward itself much better than zinc. This difference is greater in this combination of electrodes.* *Meanwhile, the solution helps prevent the cathode from getting too negative, too soon. Ions are able to move between the electrodes, and there are more ions in a calcium chloride solution, so the charge can move around more easily. This allows energy to keep transferring.*	*The highest rate of energy output would occur with copper and zinc electrodes and a calcium chloride solution.* *I selected this particular combination because a high rate of energy transfer depends on both current and voltage being as big as possible, so we want electrodes that give a larger voltage and an electrolyte solution that provides a greater current. We saw in our investigation that the combination of copper and zinc electrodes provides a relatively large voltage, around 0.9 V. Meanwhile, the data we were given shows that the calcium chloride solution provides a current of 2.24 mA. Both of these values are the highest in their data sets.* *It is important to understand why this electrode combination and electrolyte would work so well. First, the copper-zinc electrode combination has the highest electronegativity difference of the options provided--copper pulls on electrons more than the other electrodes, and zinc pulls on electrons less than the other electrodes. This means that there is a net force on electrons causing them to move to the copper electrode.* *It is also important to have a good electrolyte, because without it there is a relatively low limit to how many electrons can move to the cathode (because it would eventually become negative and not draw electrons anymore). Positive ions moving toward the cathode and negative ions moving toward the anode can help prevent this for a little longer. Calcium chloride has the most ions in a given concentration of solution and is able to keep the process going for longer. This is because there are more ions in the solution.* *Continued transfer of electrons and ions allows for continued energy transfer.*

Feedback / What to Do	*To revise toward Linking:* • Help students identify and organize evidence and scientific knowledge that relate to the problem at hand. • Review the role of the electrolyte and the role of forces in the mechanism.	*To revise toward Organizing:* • Encourage students to be more specific in their evidence and to tie it more directly to scientific knowledge. • Review the roles of electronegativity and solution concentration in the mechanism.	*To revise toward Extending:* • Ask students to consider what other factors might affect battery selection. • Ask students to model how recharging a battery works.

Lesson 10 Teacher Reference

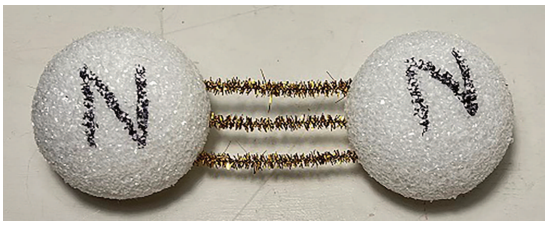
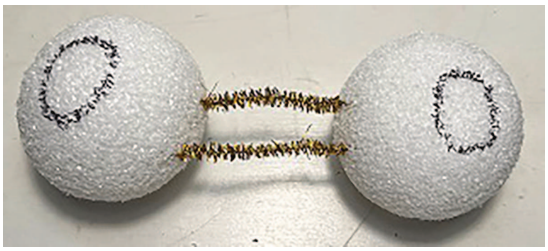
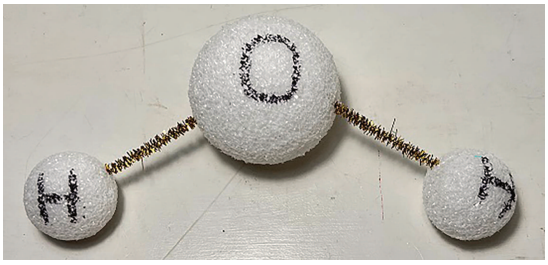
Assembling Molecular Models

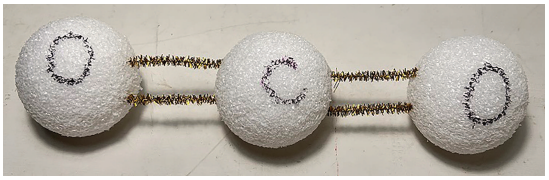
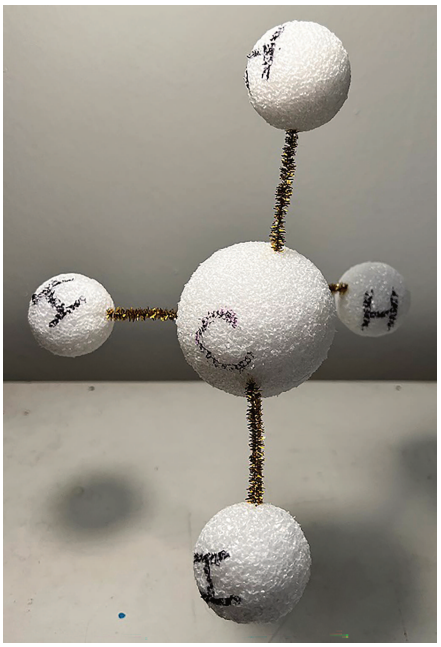
Follow these instructions to build seven sets of molecular models. Each set contains a model for nitrogen (N_2), oxygen (O_2), water (H_2O), carbon dioxide (CO_2), and methane (CH_4).

Materials needed for each set	Additional materials needed for assembly
• 9 ~2" diameter styrofoam balls • 6 ~1" diameter styrofoam balls • 15 3" pieces of pipe cleaner	• Ruler • Scissors • Black permanent marker

Instructions:

1. Use scissors to cut pipe cleaners into 3" pieces. You will need 15 3" pieces for one set of molecules.
2. Use a permanent black marker to write the atomic symbols on the styrofoam balls. You may want to write the symbol on two sides of the ball so that it is visible from several directions. Create the following for each set:
    a. 2 ~2" styrofoam balls labeled "N" for nitrogen
    b. 2 ~2" styrofoam balls labeled "C" for carbon
    c. 5 ~2" styrofoam balls labeled "O" for oxygen
    d. 6 ~1" styrofoam balls labeled "H" for hydrogen
3. Assemble molecules as shown in the table below by inserting ~1/3" of the pipe cleaner pieces into each bonded atom (styrofoam ball).

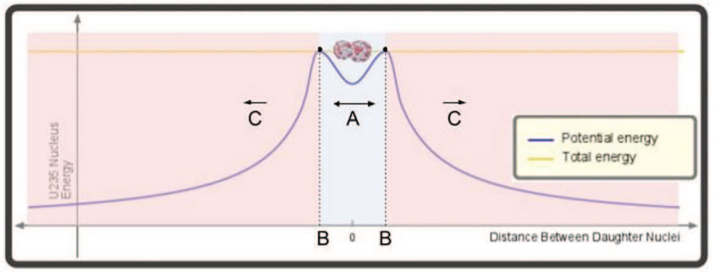
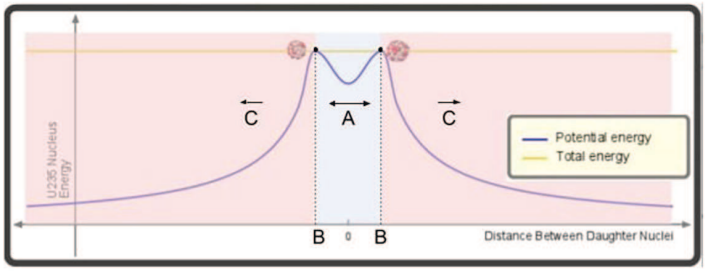
Molecular Models	
Nitrogen (N_2) 2 ~2" foam balls 3 3" pipe cleaners (three for one bond)	
Oxygen (O_2) 2 ~2" foam balls 2 3" pipe cleaners (two for one bond)	
Water (H_2O) 1 ~2" foam balls 2 ~1" foam balls 2 3" pipe cleaners	

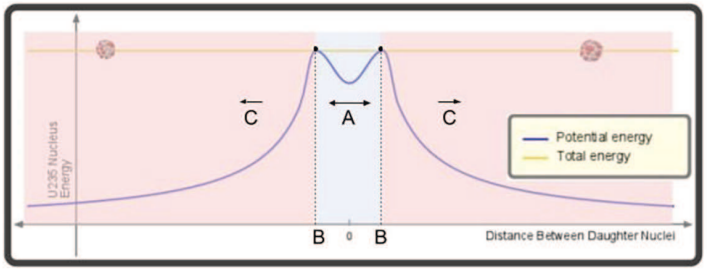
Carbon dioxide (CO_2) 3 ~2" foam balls 4 3" pipe cleaners (2x two for one bond)	
Methane (CH_4)* 1 ~2" foam balls 4 ~1" foam balls 4 3" pipe cleaners *Try to arrange the H atoms around the C of methane in a tetrahedral manner as shown.	

Simulation Mapping

How can we understand what is happening from an energy perspective?

This is what you was represented in the blue line graph shown in the simulation: https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=nuclear-fission

Description	Simulation Image
A neutron was shot at the nucleus just before this point in time. This moved the particles in the nucleus further apart and transferred enough kinetic energy into those particles that they started moving away from each other and stretching the shape of the nucleus out. The parts of the nucleus had not yet reached point B in space though. Point B in this graph would be where the peak amount of energy is stored in the field.	 PhET Interactive Simulations, University of Colorado Boulder
At this point, the parts of the nucleus have split apart and have gotten past point B in space and are now into region C. Now all the energy stored in the field from Coulombic repulsive forces between the protons starts getting transferred out of the field, speeding the two new nuclei up.	 PhET Interactive Simulations, University of Colorado Boulder

As these parts move further away from each other across region C, additional energy is transferred out of the field, resulting in a massive increase in the kinetic energy of these parts. Meanwhile, the electrostatic force causing the particles to repel decreases in strength.	 PhET Interactive Simulations, University of Colorado Boulder

The massive energy transfer in nuclear fission is actually from electric fields as protons repel, not from the fields due to the strong nuclear force. However, the energy transfer we see is much greater than in chemical reactions because of how strong the forces are between protons at these very small distances.

How does this approach contrast with typical approaches to thinking about nuclear fission?
This idea stands in contrast to the common conception that energy is released in nuclear fission because some of the mass is converted into energy. Although it is true that the "products" have a lower mass than the "reactants," this is because **rest mass is actually measuring some of the energy stored in fields** in the nucleus. As described above, this energy is transferred into the surroundings as nuclei repel. No particles are destroyed or converted into energy. It is just that the mass of the nucleus that we measure is greater than the particles that make it up because we can measure the presence of this additional energy stored in the system as additional mass. For this reason, Baierlein (2007) describes mass as a "dipstick for energy content" in the atom. The table below summarizes shifts between the more familiar approaches and this more accurate approach, which leverages students' thinking about fields.

	Typical approach	This unit's approach
Matter	A neutron is absorbed by the nucleus, resulting in a briefly largely nucleus that soon breaks apart into two smaller nuclei with free neutrons. A decrease in the total mass of the products or daughter nuclei, compared to the "reactant" or parent nucleus, may be noted but not explained, even as the number of protons and neutrons is conserved.	Same, but the briefly larger nucleus is not a point of emphasis. Conservation of matter (at the subatomic particle level) is emphasized. The decrease in apparent (rest) mass is not addressed, as it is beyond grade band.
Energy	Source of energy release may be somewhat unclear, or may be tied to energy-matter equivalence and the apparent decrease in mass that occurs in the process.	The source of energy is traced to the electric fields in the nucleus.
Forces	De-emphasized, although the strong nuclear force (and perhaps weak nuclear force) may be mentioned.	Used to help explain why the nucleus is held together until the particles in the nucleus get just far enough apart that the repulsive electrostatic force is stronger than the newly weakened strong nuclear force.

See the references below for more information on this complex idea.

References

Baierlein, R. (2007). Does nature convert mass into energy? *American Journal of Physics*, *75*(4), 320–325. https://doi.org/10.1119/1.2431183

Bondi, H., & Spurgin, C. B. (1987). Energy has mass: A common misunderstanding is re-examined. *Physics Bulletin*, *38*(2), 62–63. https://doi.org/10.1088/0031-9112/38/2/024

Lesson 11: Answer Key

L11 Electronic Exit Ticket

11.A Construct an explanation based on a variety of sources using structure-function relationships to show how protons and neutrons are conserved during nuclear fission while energy is released. (SEP: 6.2; DCI: PS1.C.1; CCC: 6.1, 5.5)				
Where these elements are addressed in this assessment	**6.2 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.	**PS1.C.1: Nuclear Processes** Nuclear processes, including ~~fusion,~~ fission, ~~and radioactive decays of unstable nuclei,~~ involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.	**6.1 Structure and Function** Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.	**5.5 Energy and Matter** In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.
Q1	X	X		
Q2		X		X
Q3				
Q4	X		X	
Q5	X		X	
Q6	X			
Q7			X	
Q8				

Question 1

Which statement best explains where the energy transferred out of nuclear fission comes from?

- The energy is transferred out of fields between protons and neutrons when the strong nuclear force "bonds" between them are broken.
- The energy is transferred out of electric fields between protons and other atoms' electrons as chemical bonds are formed.
- **The energy is transferred out of electric fields between protons because the Coulomb's law force causes protons to repel.**
- The energy is transferred out of electric fields between protons because the Coulomb's law force causes protons to attract.

Correct response: The energy is transferred out of electric fields between protons because the electric force causes protons to repel.

Rationale for distractors:
Energy is actually transferred into fields in order to break the associated "bonds."
Chemical bonds are not formed in nuclear fission.
Protons do not attract.

What to do:
Encourage students to think about what happens to bonds in a nuclear process. Ask, *Which attractions are being broken or formed? Does energy have to be transferred into or out of a field in order to break a bond?*

Support students in using explanations across contexts. Ask, *How can we explain energy transfers in nuclear fission using similar ideas to what we used to explain combustion reactions?*

Question 2

In what ways is matter conserved in nuclear fission? Select all that apply.

- **The number of protons stays the same.**
- **The number of neutrons stays the same.**
- The number of atoms stays the same.
- The type of atoms stays the same.

Correct responses:
The number of protons stays the same.
The number of neutrons stays the same.

Rationale for distractors:
Whole atoms are conserved in chemical processes, which are the only processes students have encountered before this lesson.

What to do:
Help students distinguish between chemical reactions and nuclear fission. Ask, *How is nuclear fission different from the chemical reactions we have seen in this course so far?*

Support students in thinking about conservation Ask, *What does it mean for something to be conserved? How can we use counting or math to tell that something is being conserved?*

Question 3

Do you think nuclear fission would be a good solution for powering vehicles? For providing energy for other uses? Share your reasoning.

What to look for in response:
Encourage students to think broadly about what they figured out on day 3 and connect these ideas to questions and concerns that they have.

What to do:
Accept all responses. Validating these responses engages students in activating the **relevance** and **interest** in these issues, which can motivate future questions.

Questions 4 and 5

What is the best explanation for how a nuclear reactor's structure and way of releasing energy make it less useful for a road-based vehicle, like a bus or car?

- Matter is conserved in nuclear fission.
- Large amounts of energy are released in nuclear fission.
- Protons and neutrons are held together in a nucleus with the strong nuclear force.
- **Nuclear fission requires large structures that do not easily fit on these types of vehicles.**

Explain your thinking for Question 4. What evidence do you have related to the reactor's structure and function? What would have to change for the reactor to be more practical?

Correct response: Nuclear fission requires large structures that do not easily fit on these types of vehicles.

Rationale for distractors:
These statements are all true. However, only the statement that utilizes structure-function thinking provides a rationale that can actually help explain why nuclear fission is not built into all vehicles. The other statements simply describe the process without making connections to how people could use it.

What to look for in response:
Students should cite evidence related to the reactor's structure and function. This may include ideas about the size of the reactor from *Submarine Nuclear Reactors*, about the need to have protective structures around the reactor from the jigsawed readings later in the lesson, or reasoning about how nuclear fission releases a lot of energy, as evidenced in *Nuclear Force* and the simulation, and it is hard to imagine a small, mobile structure that could safely contain the process. Students should recognize that the science of nuclear fission makes it unlikely that reactors could be placed on personal vehicles without structural changes.

What to do:
This prompt helps transition students into the more engineering-focused thinking of **Lesson 12**.

Focus students on what is being explained in the prompt. Ask, *What are we trying to figure out here? What types of evidence from the lesson might be most helpful in considering why people do what they do with this technology?*

Encourage students to make connections between structure and function. Ask, *Which one of these statements, if they were not true, would actually make it easier for us to use fission-powered vehicles?*

Question 6

How could you use criteria and constraints to explain nuclear energy to a voter who had to make a decision about a nuclear reactor to provide energy for electric vehicles?

What to look for in response: *Note: These could be different for each student.*

- We developed our criteria and constraints from thinking about different problems that are encountered around nuclear reactors.
- I can use evidence from the articles we read and the lesson to support my thinking.

What to do:
Encourage students to think about how evidence from the lesson has shaped their own thinking and how they might structure a conversation to convey this evidence to someone else.

Question 7

How did thinking about structure and function help you make sense of a nuclear reactor? In other words, what do the structures in a nuclear reactor mean for its function (how people use it)?

What to look for in response: *Note: These could be different for each student.*

- We figured out how the different parts of a nuclear reactor help transfer energy out of the system.
- We looked at different structures or particles inside atoms and how they interact in fission.
- We realized that nuclear reactors have some structures to protect people, like control rods.
- We figured out that nuclear reactors are large because of all their different parts, so they are not feasible for use in everyday vehicles.

What to do:
If students are having difficulty answering, you may rephrase "structure and function" with terminology like "different parts." You may also direct the question more toward a particular area of investigation in the lesson, like the reading about the nuclear reactor and the jigsaw readings from day 3.

Question 8

Name one student who helped you learn today. What did they do to help you learn?

What to look for in response:

- Students identify another student that helped them.
- Students articulate how that student helped them.

What to do: Depending on student responses, it may be beneficial to revisit the Community Agreements.

- If many students do not name another student, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science and engineering ideas.
- If many students do not explain what the other student did to help them, revisiting the Community Agreements may encourage students to think about what specific agreement the classmate was adhering to that caused them to be helpful.

Lesson 12: Answer Key

Rocket Fuel Argument Key

This assessment targets the following lesson-level performance expectation (LLPE):
12.A Compare and evaluate competing rocket fuel options for future space missions specifying qualitative and quantitative criteria and constraints that account for societal want of space exploration and environmental impact. (SEP: 7.1; DCI: ETS1.A.1, ETS1.A.2; CCC: 2.3)

3D Elements Addressed in this Assessment
Engaging in Argument from Evidence. Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. (SEP: 7.1)
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. (DCI: ETS1.A)
Defining and Delimiting Engineering Problems. Humanity faces major global challenges today, ~~such as the need for supplies of clean water and food or~~ for energy sources that minimize pollution, which can be addressed through engineering. ~~These global challenges also may have manifestations in local communities.~~ (DCI: ETS1.A)
Cause and Effect. Systems can be designed to cause a desired effect. (CCC: 2.3)

Scoring Guidance. The following table provides sample student responses for varied levels of understanding. These are shown in purple text in the Example row. The 3D Elements row shows which elements in the table above students should engage with while completing the evaluation. Students may not have all the components described in a level in the 3D Elements row, but if students have the majority of them, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model. Support to help students move from one level to the next is provided in the Feedback/What to Do row and the additional Ideas for Instruction table.

Write an evaluation for both nuclear and hydrogen rocket fuels to answer this question:
Is there a rocket fuel that seems to address the engineering criteria and constraints best?

- First, identify and justify the most important criteria and constraints and explain how you will rank the criteria of success. (SEP: 7.1; DCI: ETS1.A.1)
- Next, evaluate which fuel choice could achieve the goals for our future space missions. (SEP: 7.1; CCC: 2.3)
- Justify your evaluation using any measurements and/or qualitative information from this lesson and prior lessons. You may also include potential measurements that could be collected for further evaluation. (DCI: ETS1.A.1, ETS1.A.2)

	Foundational Understanding	Linked Understanding	Organized Understanding

3D Elements	The evaluation shows an explanation of chemical and nuclear rockets and restates the criteria and constraints. Students identify a rocket fuel source and tie it to some positive results.	The evaluation shows a comparison of arguments for chemical and nuclear rockets using the previously generated criteria and constraints of future space missions. Students state that their rocket fuel source helps to minimize negative impacts (e.g., environmental) and maximize positive results.	The evaluation shows a comparison of arguments for chemical and nuclear rockets using environmental impacts, cost, or other factors which are used to justify the ranking of criteria and constraints of future space missions. Students explain whether each rocket fuel source helps to minimize negative impacts (e.g., environmental) and maximize positive results. Students include a possible method of quantifiable measurements that could be taken for further evaluation.

Example	Chemical and nuclear rockets are different but can help us achieve mission success. First, they both have been used/tested and can provide the needed energy to reach our destination. How they are different is in where the energy is coming from. For nuclear rockets, liquid hydrogen is heated up, which makes it turn into a gas. One type of chemical rocket also uses hydrogen. In these rockets the liquid hydrogen is burned, which causes steam to be fired out of the exhaust. Both of these rockets are good because they meet our criteria and constraints: environmental safety, cost, and energy released.	Chemical and nuclear rockets are different but can help us achieve mission success. First, they both have been used/tested and can provide the needed energy to reach our destination. How they are different is in where the energy is coming from. For nuclear rockets, liquid hydrogen is heated up, which makes it turn into a gas. The benefit of nuclear rockets is that they don't need as many materials (hydrogen and oxygen) to fuel them. And they have a greater energy released, which means less fuel and faster travel time. But the exhaust can release radioactive particles, which makes it unsafe for Earth. One type of chemical rocket also uses hydrogen. In these rockets the liquid hydrogen is burned, which causes steam to be fired out of the exhaust. One drawback is that hydrogen rockets have less energy released than nuclear, which means you need more fuel. And travel time will be slower, which puts the astronauts at risk for cosmic radiation exposure. Both of these rockets are good but I would choose nuclear because it is less harmful for the environment than hydrogen fuels since it makes traveling safer for the astronaut (less travel time).	Sending astronauts to space will be very hard. First, most missions to space are a long way away which means the people who go will need to bring a lot of things with them. To move all of these things, the astronauts will need a lot of energy to get there and back safely. This energy will come from the fuel, so any fuel we use will need to have a high energy released. For this criterion, nuclear fuels would be the best option because nuclear fuels have a much higher energy released than either hydrogen or other chemical fuels. Because nuclear fuel releases more energy, it allows astronauts to travel through space faster and with less fuel. The decreased travel time is another important consideration because it keeps the astronauts safer from space radiation. Getting the rocket off Earth will also be important to think about because we can't pollute Earth just to get all of the materials off Earth. Here hydrogen fuels would be the best option because they release only water, while nuclear fuels release water and radioactive particles. As long as we keep the nuclear fuel out in space and don't use it to get off Earth, then our environment should be good. So, developing rockets that use both fuels--hydrogen first and then changing to nuclear after it's safe to use--might be an option to protect both the Earth from pollution and the astronauts from space radiation. A measurement that could help me support my idea is to know exactly how much fuel you'd need if you were using hydrogen or nuclear fuel. It would also be important to know how long the nuclear fuel remains radioactive after the fuel runs out.
Feedback / What to Do	*Linking:* Review the consensus Criteria and Constraints chart. Ask students to connect how these were generated and how each fuel type addresses the criteria and constraints.	*Organizing:* Review the connections between chemical- and nuclear-fueled rockets and their impacts in the global system.	*Extending:* Invite students to reflect on what criteria and constraints they see as most important and whether other interest holders, especially communities who have been disenfranchised, would give similar rankings.

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	• Have a class discussion about how each fuel proposal meets or refutes the determined criteria and constraints. • Share out the engineering goals for various non-carbon-based fuels.	• Have students work in small groups to determine types of data that could be used to further support the class's arguments. • Give students the opportunity to assess a peer's ability to justify their arguments.	• Research the cost breakdown for the use of various fuels. • Explore the engineering and structural constraints for nuclear- and hydrogen-fueled rockets.

Lesson 13 Teacher Reference

Consensus Decision Matrix

Example Consensus Decision Matrix Draft 1

Criteria/Constraints	Transportationn Method				
Safety / Health					
Cost					
Environmental Impact					
Energy Released					
Infrastructure / Availability					

Example Consensus Decision Matrix Draft 2

Criteria/Constraints	Transportation Method				
Safety / Health					
Will it explode?					
Does it cause cancer? other health issues?					
Can you transport or store it safely?					
Cost					
Cost per gram of fuel to purchase					
Cost for new engine or power plant					
Lifespan for engine or power plant					
Maintenance or storage costs					
Environmental Impact					
Direct or indirect carbon emissions					
Consequence of disposal					
Can it be recycled?					
Do byproducts of use or extraction/production affect air, soil, or water?					
Who lives in the areas most impacted?					
Energy Released					
Infrastructure / Availability					
Do storage facilities exist? Can it be stored?					
Can it be transported? How is it transported?					
How many refueling stations exist? How many do we need?					
What is required to produce the materials needed for the fuel?					

Lesson 13 Teacher Reference

STAMP Assessment Guidance

Standards Aligned Matrix of Progress
(STAMP) Protocol

The STAMP protocol was developed to provide an example of how Lesson-Level Performance Expectations (LLPEs) can include actionable opportunities for feedback. As stated in *Developing Assessments for the Next Generation Science Standards* (NRC, 2014), an assessment system that provides adequate *opportunities to learn* from teacher feedback should include formative assessment and feedback alongside more formal assessment opportunities in order to reduce inequities in science and engineering education.

STAMP protocol goals:
1) to provide **embedded formative assessment** opportunities that meet the goals of the Framework
2) to **organize evidence of student progress** on a complete PE
3) to **prevent incoherence** from the student perspective during a complex lesson sequence
4) to give each student **in-the-moment feedback** on their learning
5) to encourage teachers to practice with **new ways to organize student progress**

Preparation
This lesson set utilizes portfolio-style grading to generate meaningful feedback to students throughout the lesson set. Just like all lesson activities, each LLPE is linked to a specific set of look-fors, but for this lesson set, you will provide specific feedback via a STAMP protocol.

You will circulate at assigned times throughout the lesson to look for specific characteristics of student written work and provide stamps on their papers where you see that evidence. Generally, you will provide TWO stamps for fully-met criteria, ONE stamp for partially-met criteria, and a constructive question or prompt when you do not see sufficient evidence.

Teachers are responsible for tracking students' ultimate stamp counts. A guidance matrix is provided for teachers to see how each individual piece of evidence contributes to a larger "picture" of student progress on an NGSS PE. If you have a tracking system for your class, you may use a different system. Alternatively, students can track their own progress, report their total number of stamps, and reflect on their learning at the end of the lesson set. There is not a template provided for this, but suggested student products include the total stamps received for each lesson and one or two targeted reflection questions for each lesson in the lesson set.

Tack the lid of the stamp to the clipboard with tape, sticky tack, or another adhesive for ease of switching. Tell students to keep track of their work in a folder or binder in the event that they disagree with your portfolio assessment at the end of the unit.

The most important part of this process is integrating performance expectation-aligned teacher feedback into the moment-to-moment activities of the class.

How to use the STAMP protocol
Walk around the room and put TWO stamps on *STAMP Protocol Matrix* and students' papers if they have accomplished both/all of the look-fors. Put ONE stamp on students' papers if they have accomplished one of the look-fors or part of each look-for. If students do not get two stamps, ask probing questions to help elicit the needed ideas and direct students back to the relevant resources. If you cannot visit all students in the time allotted, see the guidance for each assessment opportunity in Lessons 13, 14, and 15 for when to check back with those students.

If you need more time to get to all students to stamp/give feedback you may have the first one or two students to get two stamps become peer reviewers.

What to do

1. Stamp students' papers or notebooks during the lesson when you see the assessment callout in the teacher guide. The slide that corresponds with this moment is indicated.
2. Provide zero, one, or two stamps (using a small ink-based stamp) next to each student's name for that assessment opportunity.
    a. Zero stamps signify developing understanding. Teachers are provided formative feedback or constructive questions to give the student. Students should keep trying and call the teacher back when they have made further progress.
    b. One stamp signifies linked understanding. Teachers should prompt the student using constructive questions in the assessment opportunity callout box. Students may call the teacher back when they have made further progress.
    c. Two stamps signify connected understanding. The student has accomplished each of the connected, three-dimensional indicators for lesson-level performance linked to the NGSS.
3. Transfer the stamp counts into the grid for each student as you circulate.
4. Look for patterns across students for a given element of the overall PE
5. Determine the student's overall progress on the three-dimensional standard by looking across the rows.

You can see the top of a sample STAMP matrix here.

Lesson 13

Look-fors	**13.A (slide J)** • Students consider the effects of implementing new transportation solutions as well as estimate the size of the effects for accessing or implementing those solutions. (DCI: ESS3.A.1; CCC: 2.4) • Students identify and compare the benefits and costs (economic, aesthetic, social, cultural, and environmental), safety, and reliability of two transportation system solutions. (SEP: 7.1; DCI: ETS1.B.1)		**13.B.1 (slides M-N)** • Students use the idea of differential effects (benefits and costs) of transportation solutions to Earth systems. (DCI: ESS3.A.2; CCC: 2.4) • Students use data and evidence to develop written arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1)		**13.B.2 (slide O)** • Students use the idea of differential effects (benefits and costs) of transportation solutions to Earth systems. (DCI: ESS3.A.2; CCC: 2.4) • Students use data and evidence to develop oral arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1)	
Students:						
Tyrique	[STAMP]	[STAMP]	[STAMP]	Missing evidence for subcategories	[STAMP]	[STAMP]
Jameela	[STAMP]	Missing trade-offs	[STAMP]	[STAMP]	[STAMP]	[STAMP]
etc...						

References

National Research Council. (2014). *Developing assessments for the Next Generation Science Standards*. National Academies Press. https://nap.nationalacademies.org/catalog/18409/developing-assessments-for-the-next-generation-science-standards

Lesson 13 Teacher Reference

STAMP Protocol Matrix

Lesson 13

LLPEs	**13.A** Compare and evaluate the potential impacts of two transportation options (current state vs. possible future state) caused by the engineering approach (shift, avoid, improve) as well as the availability and accessibility of the needed resources. (SEP: 7.1; DCI: ETS1.B.1, ESS3.A.1; CCC: 2.4)		**13.B** Present an oral and written argument for the need for specific subcategories of criteria that can be approached systematically, based on data and evidence, that shows differential effects such as benefits and costs resulting from changes in the transportation system. (SEP: 7.4; DCI: ETS1.C.1, ESS3.A.2; CCC: 2.4)			
Look-fors	**13.A (slide J)** • Students consider the effects of implementing new transportation solutions as well as estimate the size of the effects for accessing or implementing those solutions. (DCI: ESS3.A.1; CCC: 2.4) • Students identify and compare the benefits and costs (economic, aesthetic, social, cultural, and environmental), safety, and reliability of two transportation system solutions. (SEP: 7.1; DCI: ETS1.B.1)		**13.B.1 (slides M-N)** • Students use the idea of differential effects (benefits and costs) of transportation solutions to Earth systems. (DCI: ESS3.A.2; CCC: 2.4) • Students use data and evidence to develop written arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1)		**13.B.2 (slide O)** • Students use the idea of differential effects (benefits and costs) of transportation solutions to Earth systems. (DCI: ESS3.A.2; CCC: 2.4) • Students use data and evidence to develop oral arguments for the need to develop specific subcategories of criteria to make systematic decisions. (SEP: 7.4; DCI: ETS1.C.1)	
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Lesson 14

LLPEs	**14.A** Analyze data using quantitative tools to evaluate future transportation options that satisfy requirements set by society, by using numerical patterns in evidence from radar charts and cost-benefit calculations. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)	**14.B** Develop an argument for the best future transportation options that satisfy requirements set by society, by using numerical patterns in evidence and feedback from peers to refine arguments. (SEP: 6.5, 7.3; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)
Look-fors	**14.A.2 (slides M-N)** • Students use mathematical representations in their quantitative tools to track patterns in their data. (SEP: 4.1; CCC: 1.4) • Students use numerical data from quantitative tools to evaluate which options are best to use in the future. (SEP: 6.5, 4.1; DCI: ETS1.A.1, ESS3.A.2)	**14.B.3 (slide Z, *Transportation Arguments Draft*)** • Students support their arguments using patterns they observe from evidence. (SEP: 7.3; CCC: 1.4) • Students articulate how they prioritized the requirements set by society based on their personal values and the impacts of that prioritization on their decision. (SEP: 6.5; DCI: ETS1.A.1) • Students revise and/or refine their arguments for the best future transportation options. (SEP: 7.3; DCI: ESS3.A.2)

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Lesson 15

LLPEs	**15.A** Apply knowledge about the costs and benefits of resource extraction and energy and resource use and quantify them to propose vehicle systems or transportation goals designed to reduce carbon emissions and meet prioritized criteria and address trade-offs. (SEP: 6.5; DCI: ETS1.A.1, ETS1.A.2, ESS3.A.2; CCC: 2.3, 5.2)
Look-fors	**15.A.1 (slide B)** • Students propose a specific design solution for future transportation and discuss potential benefits and risks. (SEP: 6.5; DCI: ESS3.A.2) • Students' proposed vehicle or transportation systems are designed to help minimize environmental impacts. (DCI: ETS1.A.2; CCC: 2.3) • Students' design solutions quantify how it meets the specified considerations. (SEP: 6.5; DCI: ETS1.A.1) • Students' proposed vehicles or transportation systems leverage energy and matter flows while minimizing negative environmental impact. (DCI: ETS1.A.2; CCC: 5.2)

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Lesson	SEP Elements					DCI Elements						CCC Elements			
	4.1	6.5	7.1	7.3	7.4	ETS1.A.1	ETS1.A.2	ETS1.B.1	ETS1.C.1	ESS3.A.1	ESS3.A.2	1.4	2.3	2.4	5.2
Lesson 13															
13.A			x					x		x				x	
13.B.1					x				x		x			x	
13.B.2					x				x		x			x	
Lesson 14															
14.A.2	x	x				x					x	x			
14.B.3		x		x		x					x	x			
Lesson 15															
15.A.1		x				x	x				x		x		x

Lesson 15: Answer Key

Final Design Key

This end-of-unit assessment is intended to assess the Lesson Level Performance Expectation (LLPE) **15.A:** Apply knowledge about the costs and benefits of resource extraction and energy and resource use and quantify them to propose vehicle systems or transportation goals designed to reduce carbon emissions and meet prioritized criteria and address trade-offs. (SEP: 6.5; DCI: ETS1.A.1, ETS1.A.2, ESS3.A.2; CCC: 2.3, 5.2)
For information on where specific portions of this LLPE are assessed, see the **NGSS Element Alignment** table below.

Use the following rubric to assess each student's level of proficiency with each of the **NGSS Elements**. Guidance on how to provide feedback for students based on their overall proficiency and ideas for instruction are also provided.

STAMP protocol guidance for feedback on this assessment is as follows:

- Student work mainly in the Foundational Pieces category would receive ZERO stamps.
- Student work mainly in the Linked Understanding category would receive ONE stamp.
- Student work mainly in the Organized Understanding category would receive TWO stamps.

3D Elements Addressed in This Assessment
Constructing Explanations and Designing Solutions. Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations. (SEP: 6.5)
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. (DCI: ETS1.A)
Defining and Delimiting Engineering Problems. Humanity faces major global challenges today, such as the need for ~~supplies of clean water and food or for~~ energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (DCI: ETS1.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. (DCI: ESS3.A)
Cause and Effect. Systems can be designed to cause a desired effect. (CCC: 2.3)
Energy and Matter. Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (CCC: 5.2)

Over the course of this unit we have examined many different fuel options, as well as several potential future changes to our relationship with transportation. What is your final proposal for how we can improve our transportation system? In your proposal:

- State the transportation goal you chose to focus on.
- Describe the transportation option(s) you chose to meet this goal.
- Explain how your chosen option(s) transfers energy to a vehicle to allow it to move. Discuss how this is different from the current system.
    - In other words: How does your vehicle avoid energy use, shift to more desirable fuels to transfer energy to vehicles, or improve the energy transfer from existing fuels?

    - You may wish to include energy transfer models to help visualize this connection between scientific ideas and engineering thinking.
- Evaluate how well your chosen option(s) meets the current and growing need for energy from transportation while improving CO_2 emissions.
- Discuss the other criteria you prioritized when making your decision. How did they impact it? What trade-offs did you consider?
- Explain the impact you believe your proposal will have on your community and society at large, in terms of both the environmental impact and what life looks like for people. Use evidence from *Transportation Options* and your decision matrix as needed.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	+ The proposed solution is described. + Scientific ideas about energy transfer are referenced. + Criteria are partially described. + The prioritization of criteria is described and impact on the design solution is mentioned. + Likely changes to communities or around the world are described.	+ The proposed solution and its intended outcome are partially explained. + Scientific ideas about energy transfer are referenced and loosely tied to a desired outcome. + Key criteria are fully described. + The prioritization of criteria is described and impact on the design solution is mentioned. + Evidence is referenced and likely changes to communities and around the world are described.	+ The proposed solution and its intended outcome are explained, as well as how that specific solution will lead to the intended outcome. + Scientific ideas about energy transfer are used to explain how proposed solutions will lead to a desired outcome. + Key quantified criteria are fully described. + The prioritization of criteria is described and tied to its impact on the design solution. Trade-offs are described as needed. + Evidence is used to describe likely changes to communities and around the world, both environmental and societal (including economic and geopolitical). <u>Additional accurate element not essential to this item:</u> ++ In fuels that require combustion, the bonds that form must be stronger than the bonds that break or there are more of them, so more energy is released than used to break the bonds. ++ In fuels that rely on ion differentials/concentration, the relationship between electronegativities in the metals causes greater movement of electrons through a wire and of ions across a membrane, resulting in the formation of a current releasing energy out of the system. ++ In fuels that rely on fission, fields within the atom change, which results in energy being transferred out of the field.
Example	I think people should get around town using walking/biking, electric vehicles, and hybrid buses. These let you get energy without burning much stuff. That would mean less carbon dioxide is released, which would protect the environment. I also thought safety was important and went away from just biking and walking as an option so people can get around when there is bad weather or where there are not good sidewalks yet.	I focused on moving people short distances using a mix of human power, hybrid electric buses that use biofuels, and personal electric vehicles. Unlike gas, which releases energy from fields during reactions, batteries transfer energy because of moving electrons. These different technologies would release less carbon dioxide than gasoline does, while still giving vehicles the energy they need	I focused on moving people short distances (e.g., around a city). I think that we should shift from gasoline-powered individual cars to a combination of human power, hybrid electric buses that use biofuels, and personal electric vehicles. With these solutions, we are mostly shifting from gasoline to other modes in which energy is at least partially provided by batteries. In batteries, electrons and ions move from one side of the battery to the other, allowing energy to transfer. These batteries would have to be recharged using things like solar power. Because batteries are heavy and buses are large, I think in the near term it would be good to use hybrid buses that also use algae-based biodiesel, so that the carbon dioxide released

	I think my idea would make the world better. There would be less carbon dioxide released so global warming would slow down, and less pollution and more walking so people would be healthier.	to get around (or for human power, people avoiding outside energy sources altogether.) I prioritized safety as I considered different criteria, as well as infrastructure to a lesser extent. I wanted a proposal that would not require everyone to walk and bike everywhere, because not everyone can do it and it is not always healthy or a good idea if the weather is bad. Infrastructure was also important because we cannot have everyone start using the new solutions all at once, so I wanted options where the technology exists and could be easily implemented. This mix of options would help the community because there would be less pollution and people would be healthier if they drove less. It would also be safer with fewer cars on the road, since accidents are more likely with more vehicles. Globally, since walking, biking, and electric vehicles do not emit carbon dioxide when you use them, carbon dioxide levels in the atmosphere would stop going up so quickly. There would also be a lot more demand for materials for electric vehicle batteries, so like we saw earlier in the unit, that would affect mining and make it important to protect miners.	when burning the fuel is mostly used to make new fuel. Burning this biodiesel would cause more energy to be released from the fields between atoms when bonds are formed. In addition, some vehicle trips would be avoided as we improve sidewalks and bike paths to encourage people to move around more. This option would result in significantly lower carbon dioxide emissions while still providing energy needs, since it uses existing technology and is not relying on batteries improving so much and so quickly that all buses can run completely on them. A lot of the CO_2 impact would come from people shifting 10-20% of local trips to human power. I settled on this mix instead of all human power or all public transportation because I prioritized safety and accessibility, being concerned that it is not realistic to ask everyone to bike or walk everywhere, especially in low temperatures. (I had rated buses a +2 on safety because they mean fewer vehicles on the road, and the passengers are generally safer than pedestrians). Plus, a mix of different options makes it less important to switch over all the infrastructure at once. If this proposal was adopted in my community, people would be a lot healthier since they would exercise more. I think they might also be happier because there would be less traffic as more people take public transit. Pollution would decrease since there would be fewer vehicles releasing harmful gases and soot. It might take a little longer to get around if I am not using a car for every trip, but it would not be too bad if there were more buses. In greater society, the more places that adopt these solutions the less carbon dioxide released, since hybrid buses have fewer tailpipe emissions and electric vehicles and walking/biking have none. As we saw in Lesson 9, with all those EVs it would be even more important to make sure conditions in lithium and cobalt mines improved. Places that have those materials would probably start to get wealthier as these resources become more important.

Feedback / What to Do	*To revise toward Linking:* • Invite students to look back at the information contained on the transportation options slips, radar charts, and decision matrix for specific evidence, benefits, costs, and/or trade-offs.	*To revise toward Organizing:* • Invite students to use additional sources of evidence they may not have used, such as the transportation options slips, radar charts, and decision matrix. Ask students to expand on their explanations using these additional sources of evidence.	*To revise toward Extending:* • Have students consider a different goal and explain how that new goal would affect their proposal.

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	• Point out how to use the transportation options slips as a source of evidence to help evaluate the criteria and constraints in students' arguments. • Revisit the decision matrix, radar charts, and cost-benefit analysis to clarify how to use them as supportive evidence in students' arguments.	• Revisit the decision matrix and/or radar charts with the class to clarify how to use these when developing an argument (proposal). • Use the transportation options slips, radar charts, and cost-benefit analysis to help students quantify portions of their arguments that are not yet quantified (e.g., energy density, carbon emissions).	• Spend time analyzing the constraints (whether technological, social, economic, or political) that help explain why students' fuel or transportation options are not widely used at present. • Have students work together in groups (homogenous or not) to share their proposals and orally present their arguments.