EQuIP RUBRIC FOR SCIENCE EVALUATION

Energy and Nuclear Reactions

DEVELOPER: OpenSciEd

GRADE: High School **| DATE OF REVIEW:** May 2024

Energy and Nuclear Reactions

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OVERALL RATING: E

TOTAL SCORE: 8

CATEGORY I: NGSS 3D Design Score	CATEGORY II: NGSS Instructional Supports Score	CATEGORY III: Monitoring NGSS Student Progress Score
2	3	3

Click here to see the scoring guidelines.

This review was conducted by the Science Peer Review Panel using the EQuIP Rubric for Science.

CATEGORY I CRITERIA RATINGS			CATEGORY II CRITERIA RATINGS			CATEGORY III CRITERIA RATINGS		
A.	Explaining Phenomena/ Designing Solutions	Extensive	**A.**	Relevance and Authenticity	Extensive	**A.**	Monitoring 3D Student Performances	Extensive
B.	Three Dimensions	Adequate	**B.**	Student Ideas	Extensive	**B.**	Formative	Adequate
C.	Integrating the Three Dimensions	Extensive	**C.**	Building Progressions	Extensive	**C.**	Scoring Guidance	Extensive
D.	Unit Coherence	Extensive	**D.**	Scientific Accuracy	Adequate	**D.**	Unbiased Tasks/Items	Extensive
E.	Multiple Science Domains	Adequate	**E.**	Differentiated Instruction	Adequate	**E.**	Coherent Assessment System	Extensive
F.	Math and ELA	Extensive	**F.**	Teacher Support for Unit Coherence	Adequate	**F.**	Opportunity to Learn	Extensive
			G.	Scaffolded Differentiation Over Time	Adequate			

Energy and Nuclear Reactions

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Summary Comments

Thank you for your commitment to students and their science education. NextGenScience is glad to partner with you in this continuous improvement process. The unit is strong in several areas, including:

- On-ramping for transfer tasks
- Drawing on student values and community values for transport solutions
- Use and development of the physical science Disciplinary Core Ideas (DCIs).

During revisions, the reviewers recommend paying close attention to the following areas:

- **Claimed Elements.** Some claimed elements are not fully developed or used in the unit, either in learning opportunities or in assessments.
- **Differentiation Strategies**. There are many general strategies given if a student is struggling. However, there are not currently many specific interventions based on other needs of individual students.
- **Reduction of Scaffolding**. For key Science and Engineering Practices (SEPs), reduction of scaffolding is not always evident or employed.

Note that in the feedback below, black text is used for either neutral comments or evidence the criterion was met, and purple text is used as evidence that doesn't support a claim that the criterion was met. The purple text in these review reports is written directly related to criteria and is meant to point out details that could be possible areas where there is room for improvement. Not all purple text lowers a score; much of it is too minor to affect the score. For example, even criteria rated as Extensive could have purple text that is meant to be helpful for continuous improvement processes. In these cases, the criterion WAS met; the purple text is simply not part of the argument for that Extensive rating.

CATEGORY I

NGSS 3D DESIGN

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

I.B. THREE DIMENSIONS

I.C. INTEGRATING THE THREE DIMENSIONS

I.D. UNIT COHERENCE

I.E. MULTIPLE SCIENCE DOMAINS

I.F. MATH AND ELA

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

Making sense of phenomena and/or designing solutions to a problem drive student learning.

i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving.

ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems.

iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.

Rating for Criterion I.A. Explaining Phenomena/Designing Solutions	Extensive

The reviewers found extensive evidence that learning is driven by students making sense of phenomena or designing solutions to a problem. The unit supports students in making sense of a coherent series of phenomena and problems. The unit begins with students examining data about different transportation fuels, including information about their energy efficiency and their environmental impact. This sets the basis for the culminating problem of the design of the transportation system. The unit is divided into three lesson sets, with the first set focusing on how carbon-containing fuels work (Lessons 1–8), the second set focusing on how non-carbon containing fuels work (Lessons 9–12), and the third set focusing on the design of alternative transportation systems with an engineering lens (Lessons 13–15). Student questions drive the learning throughout the unit, but there are multiple missed opportunities for connection to students' prior experiences with the initial creation of the Driving Question Board (DQB) and missed opportunities to use the Progress Tracker in the last portions of the unit.

The unit introduces the anchoring phenomenon through "fuel data cards," which convey different information about a variety of fuels used in transportation. Students revisit these cards regularly throughout the unit. The second two lesson sets build on this.

- Teacher Background Information: The topic of how carbon-based fuels release energy is introduced in Lesson 1 by viewing a series of graphs and infographics about CO_2 emissions. Then students are exposed to information about a variety of different kinds of fuels used for transportation. They consider how an engine works and how that is different than other types of fuels. "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" (Teacher Edition, page 13).

- Lesson 1: "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" (Teacher Edition, page 42). The students are prompted to choose three cards at random from the deck of fuel data cards. Note that this instruction and activity is teacher directed, rather than prompting students to be motivated to "explore some of the types of fuels that have been used."
- Lesson 5: "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, it may be helpful to ask them what we ultimately want to figure out in the unit, so they remember that we care about which fuels we should use" (Teacher Edition, page 140).
- Lesson 7: "Then say, We saw on the fuel cards that the source of gasoline is oil" (Teacher Edition, page 171).
- Lesson 10: "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 handout sets of selected fuel cards 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" (Teacher Edition, page 231).
- Lesson 13: "While students are in their small groups pass out the fuel data cards to each small group and tell students to use these, Transportation System Solutions, and Transportation System Solution Drawbacks to generate any new subcategories that relate to their focal category from the Consensus Decision Matrix" (Teacher Edition, page 285).
- The second lesson set involves figuring out how non-carbon-based fuels release energy. The phenomenon is a presentation of hydrogen fuel and the use of uranium as a fuel.
- The culminating problem is to design a transportation system to reduce the harmful side effects of producing energy.
- The Progress Tracker is used across multiple lessons. This ties the topic together to the final lesson set of "How can we use what we have learned to improve our transportation system?" The Progress Tracker allows students to see how their thinking progresses as they grapple with new information within the phenomena and design solution. The Progress Tracker allows for students to connect to the problem throughout the lessons. In Lessons 14 and 15, the Progress Tracker is not used where the bulk of the solution is being figured out. This is a missed opportunity for students to use the robust Progress Tracker with all the information in it throughout the unit.

Throughout the unit, student questions and experiences drive the learning. This is done through the DQB as well as questioning in the unit. However, there are missed opportunities for students to pull from prior experiences in the initial creation of the DQB in Lesson 1. There are a few missed opportunities to have student-driven learning. There is a document "Supporting Student Questions" that groups questions by lessons (Teacher Edition, pages 337–338).

- In the first lesson of the unit, students build a DQB of their own questions about the phenomenon and revisit the DQB when the topic of investigation shifts, illustrating to students that the learning continues to relate back to their questions. A few visits may not drive student learning as authentically as would more frequent use of the DQB. There are also a few opportunities during the unit for students to add new questions to the DQB. Related evidence includes:
    - Lesson 1: The class builds the DQB with emphasis on both content-related questions and engineering design-related questions. "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… 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)" (Teacher Edition, page 48). It is possible that this note about making sure student questions come from careful observations from the lesson could stifle student questions that would come from their prior experiences and might not leverage all students' questions. "Review the directions on the slide. Distribute sticky notes and markers to partner groups. Ensure that each student saves at least one sticky note from the set their group generated to share in the Driving Question Board (DQB) activity next class…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" (Teacher Edition, page 50).
    - Lesson 3: Students add to the DQB based on new learning. There is guidance to help the teacher use these questions. "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" (Teacher Edition, page 99).
    - Lesson 7: Students revisit the DQB. "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 have addressed questions about gasoline and engines, In Lesson 3, we saw how diesel is combusted in diesel engines, and In Lessons 4–7, we made sense of why energy is transferring out of combustion reactions. Suggest that the class is in a good spot to start putting these different ideas together." However, there is not clear guidance for the teacher about what "putting these different ideas together" means at the end of Lesson 7 or the beginning of Lesson 8.

- Lesson 8: Students revise the DQB before the transfer task towards the end of the lesson. "Share DQB evaluation with a partner. Display slide Q. Give students three minutes to compare handouts and pick questions to answer. Provide students an opportunity to add any new additional questions they may have to the DQB. Students may now wonder: 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 S. Distribute a marker to each student. Read through the directions on slide R 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" (Teacher Edition, page 190). At the end of the mid-unit assessment, the teacher is prompted to consider what questions need to be looked at next. "Navigate to the next lesson. Present slide Z. 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" (Teacher Edition, page 194).
- Lesson 9: "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 from our Driving Question Board. Give students a moment to reflect on our DQB questions and then discuss the prompts as a class" (Teacher Edition, page 203).
- Lesson 10: "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 trackers. As students share ideas about carbon-based fuels and batteries, make connections to those categories on the DQB" (Teacher Edition, page 231).
- Lesson 13: "Leverage student questions to suggest that the class 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 as a whole. 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" (Teacher Edition, page 279).

  - Lesson 15: The DQB is closed out. “Return to the DQB. Display slide F. Read through the directions on Our DQB Questions to remind students on 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, they can pick a couple to write brief answers for. This will prepare them for the next step, where they will combine with other students to form a larger discussion group…Discuss DQB questions in groups. Display slide G. Have pairs from the previous step combine 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 — they 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, thumbs sideways protocol for agreement or disagreement. Then ask for a volunteer to pick 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” (Teacher Edition, page 313).
- Lesson 3: Student prior knowledge and prior experiences are used to connect to temperature and Combined Gas Law. “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…What phenomena are used as their low and high temperature reference points?…What types of situations are these scales useful in? (Teacher Edition, page 96).
- Lesson 4: Students are guided to think back on prior units, “● Think back to prior units. Where else have we seen energy input needed to start a reaction or other process? Why was that? ● Why do you think we have to put energy into the cylinder system to get the fuels to react with oxygen?” (Lesson 4 Slides, Slide 4)
- Lesson 7: “In the Space Survival Unit, we defined a bond as occurring when two atoms both pull on some of each other’s electrons. What were the types of bonds we observed? What caused these bonds to be different?” (Lesson 7 Slides, Slide E).
- Lesson 9: Students consider their prior experiences with batteries to problematize the investigation of batteries and the development of a battery design proposal. “Share personal experiences with batteries. Present slide G. Have students turn and talk with a partner about the prompts on the slide. After 2 minutes, ask for a few volunteers to share…Consider the different batteries you have encountered in your experiences. What makes a battery ‘good’ for any given use?...What do we know about the matter inside of a battery when it is working well (electricity

is flowing)?...What about when a battery is not working (electricity is not flowing)?...Motivate the need to learn more about different types of batteries based on the uncertainty in some of their initial ideas" (Teacher Edition, page 207).

- Lesson 9: "Ask, What are some things we know about the structure of an atom that would influence how 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 radii. Its row or column in the periodic table. Electronegativity. It is important that students mention electronegativity. If they do not, prompt them to think back to Space Survival Unit and this unit's Lesson 7" (Teacher Edition, page 213).
- Lesson 10: "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 emissions — a greenhouse gas. What do we know about CO 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)" (Teacher Edition, page 234).
- Lesson 11: Students are prompted to share prior knowledge about uranium to motivate investigating the structure of a nuclear reactor. "What else do you know about uranium as a fuel? Accept all responses. What are we wondering? What[sic] 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, that we 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" (Teacher Edition, page 247).

For most lessons that include engineering as a learning goal, students usually learn both engineering ideas and skills alongside Earth and space science ideas. During the third lesson set, when learning centers on the design of alternative transportation systems, students always learn both engineering ideas and skills alongside Earth and space science ideas. Lesson Level Performance Expectations (LLPEs) identify ETS and ESS DCIs as dual learning goals. For example:

- Lesson 10: "Analyze data about greenhouse gases 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)" (Teacher Edition, page 227).
- Lesson 12: "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)" (Teacher Edition, page 265). This lesson focuses on engineering DCIs in isolation.
- Lesson 14: "Analyze data using quantitative tools in order 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)" (Teacher Edition, page 289).

- Lesson 15: "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)" (Teacher Edition, page 307). ESS knowledge might be built as students design their final proposal after feedback. "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 [sic] STAMP Protocol Matrix using Final Design Key for guidance. Let students know this will be the final STAMP Protocol evaluation you will conduct. If students need more time to finalize their design proposal, you could ask students to turn in what they have, provide feedback on this, and then allow them to complete the final design proposal outside of class. Be sure to collect [sic] Final Design Proposal from students" (Teacher Edition, page 311). However, students are more likely to only be applying science DCIs previously learned.

Suggestions for Improvement

- Consider including additional opportunities for students to add questions to the DQB throughout the unit.
- Consider expanding Lesson 12 to integrate student learning of a physical science or Earth and space science learning goal.
- Consider incorporating more opportunities to explicitly pull from students' prior experiences, especially with the initial creation of the DQB.
- Consider having students revisit the DQB between Lessons 3 and 7.

I.B. THREE DIMENSIONS

Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions.

i. Provides opportunities to *develop and use* specific elements of the SEP(s).

ii. Provides opportunities to *develop and use* specific elements of the DCI(s).

iii. Provides opportunities to *develop and use* specific elements of the CCC(s).

Rating for Criterion I.B. Three Dimensions	Adequate

Science and Engineering Practices (SEPs) | **Rating: Adequate**

The reviewers found adequate evidence that students have the opportunity to use or develop the SEPs in this unit. Two elements from "intentionally developed" practice categories are only used once, which limits the development of these practices. Note that one of the SEP claims might be confusing to users. A PE claimed to be developed exclusively in this unit includes an element of **Developing and Using Models**. This element is used and developed multiple times in the unit but is not itself claimed separately in the unit. In addition, some claimed elements are not fully used by students.

Asking Questions and Defining Problems

- *Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.*
  - Lesson 1: "What question(s) do you have about the science behind the phenomena we have explored so far?" (Lesson 1, Slide S).
- *Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.*
  - Lesson 1: Students consider ways that engineering, and science can help decrease the amount of CO_2 emissions from transportation. "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" (Teacher Edition, page 49).

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.* This element is part of **HS-PS1-4**, which the materials state is not developed in other units or courses. However, this element is not listed as a key element on Teacher Edition, pages 18–19, so there may be confusion about its use in this unit
  - Lesson 1: "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" (Teacher Edition, page 44). The class develops a consensus model. "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" (Teacher Edition, page 46).
  - Lesson 2: "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" (Teacher Edition, page 63). Then, students use prior knowledge of the relationship of matter, energy, and force to revise their models again. "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" (Teacher Edition, page 67).
  - Lesson 2: "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" (Teacher Edition, page 75).
  - Lesson 2: "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" (Teacher Edition, page 79). Students are also asked, "Be sure to include the ideas from previous models, such as: What inputs are added to the system? How does matter change through the system? What outputs are generated by the system? Cite specific evidence from the lesson and explain how this evidence prompted you to revise your model."
  - Lesson 4: Students complete models of how energy is transferred in a collision. "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" (Teacher Edition, page 111).

- ○ Lesson 6: Students use a computer simulation and are asked to provide evidence. "3. What evidence is there in the model that shows you that energy is conserved?" (Lesson 6 Handout Modeling Energy Changes, page 1).
- ○ Lesson 8: "With your class 2. In silence, as a class sort and organize ideas by category: ○ components; ○ relationships or interactions; ○ or, mechanisms" (Lesson 8 Slides, Slide D). "Develop models in pairs. Present slide F. Help students start the model by drawing the substances involved in the reaction. Highlight to students how you can represent gasoline by just showing 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" (Teacher Edition, page 182).

- *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.*
  - ○ Lesson 5: Students use a simulation model and a physical model that both show the movement of matter and energy into and out of a system. "You used two different models to investigate bond formation: the ruler and marble system and the simulation. What are the merits and limitations of each of these for modeling, investigating, and explaining energy transfer during bond formation?" (Lesson 5 Handout Predicting Energy Changes, page 3). Students are also told, "Use your models and data to assess the claim 'the energy released when carbon-based fuels burn is due to bond formation'….State the evidence you have available (models and data)." Students might therefore move between models as they assess the claim.

Analyzing and Interpreting Data

- All elements claimed in this practice category are claimed as being "intentionally developed" in the unit.
- *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.*
  - ○ Lesson 8: Students use mathematical models (mole ratios) to calculate carbon emissions. "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 Calculating Carbon Emissions in pairs" (Teacher Edition, page 187).
  - ○ Lesson 14: Students use a 5-point rating system. "Rate options on the financial cost using evidence. Present slide J. Give groups 5 minutes to rate their top 5 options on financial cost, just as they did as a class with the example option, using the information provided on Transportation Options. Remind students to refer back to the subcategories they developed in Lesson 13" (Teacher Edition, page 297). "Explain that the overall analysis will differ between students in the same group, based on the individual students' values rating for each criterion. 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 their handouts. Have students complete cost-benefit analyses for their group's top five transportation options. Present slide S. Give students 3 minutes to complete the cost-benefit analysis for their first transportation option on Cost-Benefit Analysis. Remind them that their individual values ratings also need to be factored into each criterion and constraint. Encourage students to have yourself or a peer check their work before moving onto a cost-benefit analysis for another transportation option. Present slide T when all students have successfully completed one cost-benefit analysis calculation so they know to move onto the calculation tables for the rest of their options" (Teacher Edition, page 300).

- *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.*
  - Lesson 1: Students get new data throughout this lesson that they apply to their knowledge of fuels. "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 solutions (SEP: 4.5)." This element is not claimed as a LLPE, but guidance is provided that helps students begin to build toward this element in this lesson.
  - Lesson 3: "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….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" (Teacher Edition, page 93). Students then use the new data collected and apply it to trends between air properties as well as attempt to explain the fire syringe demonstration. "Can we use these property trends (point to the Air Property Trends chart) to explain the Syringe Piston Demonstration?" (Teacher Edition, page 95).
  - Lesson 4: Students consider the new data and how it impacts their understanding. "How does this new data affect your understanding of the cylinder system?" (Teacher Edition, page 110). Students discuss new data from their investigation. "1. How did changing the amount of energy you transferred into the marble system affect the outcome? 2. What data did you use to come to your answer? 3. How does this new data affect your understanding of the cylinder system?" (Lesson 4 Slides, Slide K).
  - Lesson 10: "Direct students' attention to the Criteria and Constraints poster 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 gases. If needed, point to the statement about CO emissions and ask, Is it just CO 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 [sic] Progress Tracker" (Teacher Edition, page 238).
  - Lesson 11: Students use data from the reading Nuclear Forces to help them better understand the simulation. "Suggest that the reading might help us better understand the ideas in the simulation…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" (Teacher Edition, page 256). "How can the forces help explain what we see in terms of energy transfer into and out of fields? How is this relationship between forces and energy similar to what is happening in chemical reactions?" (Teacher Edition, page 258).

- *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*.
    - Lesson 2: "Small groups work on Fuel Data Comparison….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" (Teacher Edition, page 82).
    - Lesson 10: Students use data regarding hydrogen in the atmosphere to consider criteria and constraints. They revisit the fuel cards of fuels they have already visited (gasoline and lithium-ion batteries) as well as hydrogen. They review the cards using prompts on a slide. They use data from Hydrogen Fuel Cells and Comparing Different Batteries to analyze data. "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)" (Teacher Edition, page 233).
    - Lesson 14: Students use cost-benefit analysis. "Have students select one transportation option to analyze first. Give each group 2 minutes to complete step 1 as outlined on Cost-Benefit Analysis. This consists of recording their top 5 transportation options in the titles of each Calculation Table and choosing one of the transportation options to start analyzing before jumping into all five. Factor in personal importance of criteria individually. Present slide P. Give students 2 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 ratings of each criterion into the calculation table. Give each group 3 minutes to complete steps 3 and 4 as outlined on Cost-Benefit Analysis. They will directly take the ratings they gave for each criterion from the Decision Matrix and multiply those ratings by their personal values rating. Demonstrate a cost-benefit analysis calculation. Present slide Q. Explain that the overall analysis will differ between students in the same group, based on the individual students' values rating for each criterion. Use the example calculation on slide R to show how to complete step 5 on [sic] Cost-Benefit Analysis. Students will see the same sample calculation on their handouts" (Teacher Edition, page 300).

Constructing Explanations and Designing Solutions. All elements claimed in this practice category are claimed as being "intentionally developed" in the unit.

- *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.*

- Lesson 2: Students construct an explanation from their own theories and prior knowledge. "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." (Teacher Edition, page 63). Later in the lesson they revise their explanations based on the model of the piston of a vehicle engine. "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" (Teacher Edition, page 65). Students also complete an activity. "In your notebook ● Observe the Syringe Piston Demonstration. ● After you observe the demonstration, answer these questions: ○ What happens to the syringe volume? ○ What evidence of forces do you see? ○ What is causing the forces? ○ How is energy transferred by the forces?" (C.5 Lesson 2 Slides, Slide Z). Students are not prompted to assume that theories and laws that describe the natural world are consistent throughout time.
- Lesson 11: There is a whole class discussion to consider an explanation for how a nuclear reactor works after looking at the Submarine Nuclear Reactors Resource (Teacher Edition, pages 247–248). "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" (Teacher Edition, page 249). There is another whole class discussion where students construct explanations using the simulation results as their evidence (Teacher Edition, page 253). Students end with an Exit Ticket. "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? …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?...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?" (Teacher Edition, page 419). However, this task asks students to use argumentation rather than constructing or revising explanations for phenomena.

- *Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.* This element is cited as a practice that is "intentionally developed" but it is only claimed once in the unit. It is also not clear that it is used, as nuclear power's impacts are not "unanticipated."

- Lesson 11: "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" (Teacher Edition, page 260). The dangers of nuclear radiation and nuclear power are not unanticipated, they are just unknown to students who have not followed the full OpenSciEd high school course sequence. A student who previously studied OpenSciEd unit P.2 or P.5 would be able to anticipate these effects. Students may also have prior knowledge of the downsides of nuclear energy from their social studies classes or from discussions of nuclear energy in the media. Students complete the Progress Tracker. "Update progress trackers. Present slide Z. Give students a few minutes to update Comparing Fuels, then share out if there is time. A sample entry is shown below" (Teacher Edition, page 260). One of the columns is 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."

- *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.*
  - Lesson 5: Students use the marble models as evidence to connect claims and evidence. "What evidence did you observe that suggests there is a change in energy in the system when a bond forms?" (Teacher Edition, page 131). They use the models more and consider the evidence after they discuss with a partner. "Where did your models agree? Where did your models disagree? Do you think the distance matters?" (Teacher Edition, page 113). Later in the lesson students use the models independently to assess a claim. "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 question on Predicting Energy Changes. Tell them that if they need to, they can use models to help them with 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" (Teacher Edition, page 138).
  - Lesson 7: Students use models and science reasoning as they discuss bone strength and energy transfers, using evidence from a previous class. "How does your amount of energy transferred compare to established value? Why might the established value be different than ours? Why might the established value be negative? Where did the energy that's transferred out come from? Where is it going?... Would this transfer of energy result in the surrounding air molecules in the cylinder system to speed up or

slow down? If you started with two moles of methane and four moles of oxygen, why would it affect the total energy transferred?" (Teacher Edition, pages 168–169).

- *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.*
    - Lesson 9: Students develop a battery design proposal. "Make a battery design proposal. Display slide DD. Suggest that our combination of electrolytes we analyzed today and metals we measured yesterday give us the kind of data that engineers use to try to figure out how to design more effective batteries. Tell students to draw on that data and their investigation data to support a battery design proposal they would make in answer to 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 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 submit their design proposal" (Teacher Edition, page 223).
    - Lesson 14: Students refine their solutions by tracking fuels using the criteria. Later in the lesson, students interpret radar charts for their top options. "Have students work in groups to record observations about the radar charts they generated in their notebook. Then, remind them to use those observations to support their interpretations of the data. Give students 3 minutes to work in their groups and take 2 minutes to have students share some of their interpretations out to the class" (Teacher Edition, page 298). Later in the lessons, students analyze the options. "Have students complete cost-benefit analyses for their group's top five transportation options. Present slide S. Give students 3 minutes to complete the cost-benefit analysis for their first transportation option on Cost-Benefit Analysis. Remind them that their individual values ratings also need to be factored into each criterion and constraint. Encourage students to have yourself or a peer check their work before moving onto a cost-benefit analysis for another transportation option. Present slide T when all students have successfully completed one cost-benefit analysis calculation so they know to move onto the calculation tables for the rest of their options" (Teacher Edition, page 300).
    - Lesson 15: "Finalize design proposals. Display slide B. Say, We have spent a lot of time thinking about trade offs[sic], our values, impacts on others, and evaluating possible ways to improve our relationship with transportation. Now it is time to put it all together. You will create a final 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" (Teacher Edition, page 311).

Engaging in Argument from Evidence

- All elements claimed in this practice category are claimed as being "intentionally developed" in the unit.

- *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.*
    - Lesson 9: Students compare and evaluate arguments about EVs. "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 coparticipant 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" (Teacher Edition, page 204).
    - Lesson 12: "Students argue their fuel choice using evidence. Display slide H, pass out [sic] Rocket Fuel Argument, and tell the students that they will now be arguing which fuel choice, if any, meets the needed criteria and constraints for an optimal rocket fuel. Students' argument[sic] should begin by defining the problem this fuel choice is looking to overcome, followed by which, if any, fuel they would recommend for our Mars missions, and their rationale for this choice" (Teacher Edition, page 273). "Write an evaluation for both nuclear and hydrogen rocket fuels answering the following question: Is there a rocket fuel that seems to address the engineering criteria and constraints best? Be sure to: Start your evaluation by identifying and justifying the most important criteria and constraints and explaining how you ranked the criteria of success. Then make an evaluation for which fuel choice should be made for our future space mission. Justify your evaluation using any measurements, or qualitative information from this lesson, past lessons. You may also include potential measurements that could be collected to be used for further evaluation" (C.5 Lesson 12 Assessment Rocket Fuel Argument).
    - Lesson 13: Students use the Utilizing Decision Matrix. "Have students copy the class consensus decision matrix into [sic] Utilizing Decision Matrix, then describe how the transportation solution meets or fails to meet each of the class's criteria and constraint groupings" (Teacher Edition, page 283). "Work with your group to explore a transportation solution meant to curb our carbon emissions. ● Consider: ○ Engineering goal addressed ○ Supportive evidence for plan ○ Possible trade-offs made ○ Barriers in resource availability" (C.5 Lesson 13 Slides, Slide D).
- *Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.* This element is cited as a practice that is "intentionally developed" but it is only used once in the unit.
    - Lesson 5: "Evaluate the argument. According to the reading, what are the advantages of fossil fuels over biofuels for transportation? Do you agree with the writer's reasoning about these advantages? What important information about fossil fuels was left out of

this argument?....According to the reading, what are the advantages of biofuels over fossil fuels for transportation? Do you agree with the writer's reasoning about these advantages? What important information about biofuels was left out of this argument?" (C.5 Lesson 5 Handout Comparing Fuels, page 3). Students debrief their arguments about fuels. "Why might we want to use one fuel over the other? What criteria and constraints must we consider when thinking about how to improve our fuel or transportation systems? Why is it so important to think about where the energy in fuels comes from?" (Teacher Edition, pages 141–142).

- *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.*
  - Lesson 7: "Lead a class discussion in order to use the sensemaking of Lesson 6 with the combustion reaction systems of diesel and gasoline, using the prompts below…How is the combustion system above similar to the 'marbles' in the sim? How is it different? As the gasoline combusts, how do we know energy transfers out of the reaction? What might this outward transfer mean for the bond strength of reactants versus products?" (Teacher Edition, pages 161–162). These questions do not have students provide or receive critiques even though this element is claimed in the assessment opportunity box. Later in the lesson students share their claims and are encouraged to counter claims (provide and receive critiques). "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 partner during the investigation from the last lesson step. Use the prompts below to lead a whole class discussion. As students share, give them opportunities to respond to and counter each others' claims using evidence. Consider allowing students to write their ideas before sharing if time allows" (Teacher Edition, page 165). "Ask, using what we have seen and learned over the last few lessons, what critiques would you offer to a student who provided an answer to the following question? As you and your partner generate these critiques, be sure to consider how it can be phrased in order for your feedback to be respectful and constructive to this student. Listen for these ideas: Providing 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 are being formed. The student needs to consider the difference between energy transferred into broken bonds and energy transferred out of formed bonds" (Teacher Edition, page 166). "What critiques would you offer to a student who provided this answer to the following question: Using the differences in bond strengths, which reaction system would likely result in more energy being transferred out the reaction? ● Weak bonds breaking forming strong bonds. ● Weak bonds breaking forming medium bonds. ● Medium bonds breaking forming strong bonds" (C.5 Lesson 7 Slides, Slide J). This critique is not fully aligned with this SEP element because students are only providing feedback to fictional students and not receiving feedback.

Additionally, students are not presented with diverse perspectives or asked to determine additional information that would be helpful.

- Lesson 14: Students prepare and share arguments about which proposal/solution they think is best. They then revise their argument. There is a protocol for students to give and receive critiques on their arguments. "Explain the Stand Up-Hand Up-Pair Up protocol. Present slide X. Talk through the slide to explain the protocol students will use to share their arguments. Explain that they will have 6 minutes in each pair; 1 minute for person 1 to share their ratings, 1 minute for person 2 to repeat ideas and ask questions, and 1 minute for person 1 to respond to person 2. Ask students if they have any clarifying questions before starting the activity. Have a 1 minute timer for students to help them keep on track with their timing. Have students repeat this two more times so they meet with a total of 3 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 [sic] STAMP Assessment Guidance when they turn in [sic] 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" (Teacher Edition, page 302).

- *Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.*
    - Lesson 6: Students make an oral argument, but do not produce a written argument. "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… 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" (Teacher Edition, pages 155–156).
    - Lesson 13: Students share orally and write arguments in small groups about their subcategories. "After five minutes, pair groups together to form larger groups. Each small group should share the subcategories and reasons for including them. Then as a larger group they 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 [sic] STAMP Protocol Matrix" (Teacher Edition, page 285).

Disciplinary Core Ideas (DCIs) | **Rating: Adequate**

The reviewers found adequate evidence that students have the opportunity to use or develop the DCIs in this unit. Many DCI elements are used and developed throughout the unit. However, some claimed elements are not fully used or developed.

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*.
  - Lesson 4: "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" (Teacher Edition, page 111).
  - Lesson 6: This element was not claimed but was built toward. Students connect this DCI element to the simulation. "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" (Teacher Edition, page 155).
  - Lesson 8: Students model carbon-based fuel combustion with pairs and as a class. "How should we represent the mechanisms? Describe how the energy in fields change as the forces change. Note that new bonds form because they are stronger/more stable" (Teacher Edition, page 184).

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.*

- Lesson 8: Students take the transfer task with hot/cold packs. “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 below: You do not need to perform any calculations with energy…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?” (Teacher Edition, pages 379–381)
- Lesson 2: Students consider what is happening within an engine in terms of a chemical process. “What matter changes are occurring inside the cylinder system?...What evidence do you see of energy transfer into and out of the cylinder system?...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” (Teacher Edition, page 67).
- Lesson 4: Students complete an Exit Ticket that considers atoms in molecules as the bonds between them break. “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” (Teacher Edition, page 120).
- Lesson 6: Students model energy changes. “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” (Teacher Edition, page 153). Although this task addresses energy changes during collisions, it does not address the rearrangement of atoms into new molecules.

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.*
    - Lesson 11: "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" (Teacher Edition, page 252).

PS3.A: Definitions of Energy

- *At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.*
    - Lesson 1: Students consider their models using Matter-Energy-Forces (M-E-F) thinking. "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…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 [sic] Electrostatics Unit in Lesson 4 to remind students of prior sensemaking using fields" (Teacher Edition, page 45). Later in the lesson, students "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[sic]. 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" (Teacher Edition, page 48).
    - Lesson 3: Students consider the transfer of energy in the piston. "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.…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" (Teacher Edition, page 93). Later in the lesson students are asked in a class discussion that leverages M-E-F thinking. "Where and how is energy being transferred to the air particles?...What happens after energy is transferred into the system?" (Teacher Edition, page 98).

- *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.~~
    - Lesson 1: "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[sic]. 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" (Teacher Edition, page 48).
    - Lesson 9: Students use this element when considering their battery design proposal. "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 why" (Teacher Edition, page 223). The ideal student response for organized understanding involves explaining the movement of electrons (Teacher Edition, pages 408–409).

PS3.B: Conservation of Energy & Energy Transfer

- *Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems*.
    - Lesson 3: This element is not claimed in this lesson but is partially used. Students complete Air Property Data and look at CODAP data. In a class discussion for consensus there are questions that are asked that relate to this. "What energy transfers happen during those collisions?...Where and how is energy being transferred to the air particles?... 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?" (Teacher Edition, page 98).
- *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.*

- Lesson 3: This element is not claimed in this lesson but is partially used. Students use Combustion of Methane and guiding questions. "When students have finished, say, Energy transfer in a chemical reaction is dependent on many factors beyond just 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. Show slide P and run a class discussion over the analysis questions using the prompts below: Would this transfer of energy result in the surrounding air molecules in the cylinder system to speed up or slow down? How might this then affect the pressure exerted on the piston in the cylinder system? Does matter leave this system? Does energy? If you started with two moles of methane and four moles of oxygen, why would it affect the total energy transferred? How much energy might we expect to be transferred if we have one mole of methane and 2 moles of oxygen?" (Teacher Edition, page 169). "Pass out Fuel Energy Released and Bond Energies. Give students about ten minutes to complete the calculations and debrief questions. ✱ Display slide R and carry out a whole group discussion explaining the observed energy released values for gasoline and diesel" (Teacher Edition, page 170).
- Lesson 7: "How might 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 released[sic] from forming bonds. Subtract the two numbers to determine the difference" (Teacher Edition, page 168).

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.*
  - Lesson 4: "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….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" (Teacher Edition, page 111). Later in the lesson students consider fields. "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...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 [sic] Energy Graph" (Teacher Edition, page 115).

  - Lesson 5: Students observe and make sense of the marble interactions. "Determine where energy transfers are occurring. Discuss the prompts on slide E as a class" (Teacher Edition, page 130). Later in the lesson, there is an alternate activity to support this element. "If your students are struggling to describe the role of forces, use https://lab.concord.org/embeddable.html#inter actives/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" (Teacher Edition, page 135).
  - Lesson 6: Students use this element in Modeling Energy Changes. "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….Then elicit ideas from students… When is energy in the field at its greatest? At its least?" (Teacher Edition, page 153).
  - Lesson 11: "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" (Teacher Edition, page 258).

ESS3.A Natural Resources

- *Resource availability has guided the development of human society.*
  - Lesson 5: "The modern world would not exist without fossil fuels because of how they have increased people's access to energy….Currently, biofuels are made primarily from corn and soybeans, which means some food crops, water, and other resources are diverted to make biofuels, but future biofuels may be made primarily from algae and food waste" (C.5 Lesson 5 Handout Comparing Fuels, pages 3–4).
  - Lesson 11: In the Where are We Going and NOT Going section, there is guidance on this element. "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[sic]" (Teacher Edition, page 245).
  - Lesson 13: The words "the development of" in the DCI are not claimed in this lesson. Students use the design matrix to consider criteria and constraints for the different transportation solutions (Teacher Edition, page 284). In the STAMP Protocol guidance,

teachers should look for this element when analyzing student responses. "Students consider the effects of implementing a new transportation solution as well as estimate the size of effect for accessing, or implementing those solutions (DCI: ESS3.A.1; CCC: 2.4)" (Teacher Edition, page 428).

- *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.*
    - Lesson 11: Students add to Progress Trackers as they consider risks and benefits of different fuels. "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. Update [sic] progress trackers. Present slide Z. Give students a few minutes to update Comparing Fuels, then share out if there is time. A sample entry is shown below" (Teacher Edition, page 260).
    - Lesson 13: The STAMP protocol uses this element. "As students examine the 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 readings or the data on the fuel cards" (Teacher Edition, page 286).
    - Lesson 14: Students rate fuels based on different risks and benefits. "K. Give groups the remainder of the class period to rate their options on the remaining four criteria (energy released, safety, environment, and infrastructure) using the information provided on Transportation Options" (Teacher Edition, page 297). "Have students complete cost-benefit analyses for their group's top five transportation options….Remind them that their individual values ratings also need to be factored into each criterion and constraint" (Teacher Edition, page 300).
    - Lesson 15: Students consider costs and risks of a transportation system as well as the benefits. "Evaluate how well your chosen option(s) meets the current and growing need for energy from transportation while improving CO emissions. Discuss the other criteria you prioritized when making your decision. How did they impact it? What tradeoffs did you consider? Explain the impact you believe your proposal will have on your community and society at large. Use evidence from your design matrix as needed" (Lesson 15 Handout Final Design Proposal).

ESS3.B 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.*
    - Lesson 5: Students read about biofuels and fossil fuels. Sample student responses for the questions include "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" (Teacher Edition, page 141). The reading explains how fossil fuels are formed via text and a model. There is text "It has allowed us to increase agricultural production to support a larger population, as well as house and easily move people around the world" (Lesson 5 Handout Comparing Fuels) It is not clear that this is a geologic EVENT that has shaped human history.
    - Lesson 8: Students debrief and consider the relationship between fuel type and carbon dioxide emissions. They consider how climate change and people are impacted. This element is claimed for this discussion in the assessment box (Teacher Edition, page 188). However, there is not a clear connection to a geologic EVENT and how that shapes the course of human history.

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.*
    - Lesson 1: Students consider this with the avoid-shift-improve framework. "Introduce the Avoid-Shift-Improve framework….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 markers to partner groups" (Teacher Edition, page 50).
    - Lesson 9: Students consider the benefits and drawbacks of EVs as a solution. "Take 4 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 improve the charging technology" (Teacher Edition, page 205).

- Lesson 10: Students consider hydrogen when considering emissions and comparing them to other pollutants. "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 is only present at 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 from other substances that have it. Give students a couple 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)" (Teacher Edition, page 233). "If hydrogen is made from water, the only other product is oxygen which we need to breathe!" (Teacher Edition, page 234) There is not a thorough discussion of this element in this part of the lesson. The materials provide a possible entry in the student Progress Tracker. "Shift: Produce more hydrogen from water using renewable sources of electricity. Provide more hydrogen refueling stations."

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.*
    - Lesson 10: Students use the Progress Tracker and the engineering implications of the avoid-shift-improve framework. "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 gases. 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" (Teacher Edition, pages 238–239). In this performance, students don't show evidence that they understand that criteria and constraints should be quantified.
    - Lesson 12: Students discuss why they should rank the criteria and constraints. "Say, I heard ideas about different criteria and constraints that we will have to make about the fuel that powers our next-generation rockets. As we look at these different criteria and constraints, do we look at each of them equally or are some of greater importance? ... Say, Now that we have a way of comparing the different fuel choices for future space missions. Let's apply this tool in a personal evaluation for nuclear and hydrogen rockets" (Teacher Edition, page 271). "Students argue their fuel choice using evidence. Display slide H, pass out [sic] Rocket Fuel Argument, and tell the students that they will now be arguing which fuel choice, if any, meets the needed criteria and constraints for an

optimal rocket fuel. Students' argument[sic] should begin by defining the problem this fuel choice is looking to overcome, followed by which, if any, fuel they would recommend for our Mars missions, and their rationale for this choice" (Teacher Edition, page 273).

- Lesson 14: "Have students identify which of the categories of criteria they see as more or less important to consider when examining solutions. Have students refer to what was discussed in the previous step to help them rate these values, 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" (Teacher Edition, page 296). Students rate fuels based on different risks and benefits. "K. Give groups the remainder of the class period to rate their options on the remaining four 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 in their notebook" (Teacher Edition, page 297). Students complete a cost-benefit analysis. "Have students complete cost-benefit analyses for their group's top five transportation options. Present slide S. Give students 3 minutes to complete the cost-benefit analysis for their first transportation option on [sic] Cost-Benefit Analysis. Remind them that their individual values ratings also need to be factored into each criterion and constraint. Encourage students to have yourself or a peer check their work before moving onto a cost-benefit analysis for another transportation option. Present slide T when all students have successfully completed one cost-benefit analysis calculation so they know to move onto the calculation tables for the rest of their options" (Teacher Edition, page 300).

- *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.*
  - Lesson 12: The last sentence of the DCI element is not claimed in this lesson. "Students argue their fuel choice using evidence. Display slide H, pass out [sic] Rocket Fuel Argument, and tell the students that they will now be arguing which fuel choice, if any, meets the needed criteria and constraints for an optimal rocket fuel. Students' argument[sic] should begin by defining the problem this fuel choice is looking to overcome, followed by which, if any, fuel they would recommend for our Mars missions, and their rationale for this choice" (Teacher Edition, page 273). Although the lesson addresses the environmental impact of different fuels for rockets, there is little information on this topic in the readings.
  - Lesson 15: Students finalize design proposals. "Say, We have spent a lot of time thinking about trade offs[sic], our values, impacts on others, and evaluating possible ways to improve our relationship with transportation. Now it is time to put it all together. You will create a final proposal for a transportation goal or option that you believe is the most important or impactful. Distribute [sic] Final Design Proposal. Let students know

that they can use any materials from the unit to help support the development of their design proposals" (Teacher Edition, page 311).

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.*
    - In Lessons 13–15, students use criteria and constraints and rank them (see additional evidence above). They therefore might begin to build toward this understanding.

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.*
    - Lesson 13: "Break criteria/constraint categories into subcategories. Display slide L. Distribute Transportation System Solution Drawbacks and give students a moment to read their previously assigned section. Have students work with their group to come up with three to four subcategories for the criteria/constraint grouping that is most relevant to their transportation solution. Have students record these in their science notebooks…Furthering subcategories. Display slide M. While students are in their small groups pass out the fuel data cards to each small group and tell students to use these, Transportation System Solutions, and Transportation System Solution Drawbacks to generate any new subcategories that relate to their focal category from the Consensus Decision Matrix. Then, in their notebooks, they 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 the subcategories and reasons for including them. Then as a larger group they will come to consensus on what to include on a list of subcategories that they will present to the class" (Teacher Edition, page 285).

Crosscutting Concepts (CCCs) | Rating: Adequate

The reviewers found adequate evidence that students have the opportunity to use or develop the CCCs in this unit. Students have opportunities to use grade-appropriate elements of the CCCs. Many claimed elements within assessment boxes are whole-group discussions, limiting the evidence of use of the elements for some students. Some claimed CCC elements are not fully used or only claimed once in the unit, resulting in little development of the element.

Patterns

- *Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.*
    - Lesson 1: "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)" (Teacher Edition, page 43).
    - Lesson 2: "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 [sic] Fuel Data Comparisons. Tell students to be prepared to share the graph(s) that helped them answer the investigation question" (Teacher Edition, page 82).
- *Mathematical representations are needed to identify some patterns.*
    - Lesson 14: Radar charts are used to compare solutions. "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" (Teacher Edition, page 298).
    - Lesson 14: Students use a mathematical formula to calculate a cost-benefit analysis. "Introduce the idea of a cost-benefit analysis. Present 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 identify if a solution is overall beneficial or not" (Teacher Edition, pages 299–300).

Cause and Effect: Mechanism and Prediction

- *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.*
    - Lesson 2: Students look at a CODAP data set to observe and predict air pressure, temperature, and volume relationships. Later in the lesson, there is a discussion. "Compressing air increases its temperature. How do we know there is energy in the diesel cylinder system? Are the air particles the only thing moving? OK, so forces transfer energy (point to M-E-F triangle). What forces are acting on the air particles? What energy transfers happen during those collisions? Where and how is energy being transferred to the air particles? 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? Do we know why that happens?" (Teacher Edition, page 98).
    - Lesson 3: "If we had access to volume, temperature, and pressure data for a fixed amount of air, what trend 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?" (Lesson 3 Slides, Slide G).
    - Lesson 3: "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. OK, so forces transfer energy (point to M-E-F triangle). 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. 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 happens after energy is transferred into the system? Combustion. There's a reaction. The fuel is ignited and starts burning" (Teacher Edition, page 98).

  - Lesson 7: "Would you predict gasoline or diesel to have a greater energy released values per mole? Diesel releases more energy than gasoline. Revise the following claim to reflect a more supported claim. Diesel transfers more energy because weaker bonds are breaking and stronger bonds are forming. Diesel transfers more energy because more stronger bonds are formed than 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" (Teacher Edition, page 170).
  - Lesson 9: "Suggest that our combination of electrolytes we analyzed today and metals we measured yesterday give us the kind of data that engineers use to try to figure out how to design more effective batteries. Tell students to draw on that data and their investigation data to support a battery design proposal they would make in answer to 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 why" (Teacher Edition, page 223).
- *Systems can be designed to cause a desired effect.*
  - Lesson 9: "Make a battery design proposal. Display slide DD. Suggest that our combination of electrolytes we analyzed today and metals we measured yesterday give us the kind of data that engineers use to try to figure out how to design more effective batteries. Tell students to draw on that data and their investigation data to support a battery design proposal they would make in answer to the question: Which two metals and electrolyte solution combined should produce the highest rate of energy output in a battery?" (Teacher Edition, page 223)
  - Lesson 10: "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?" (Teacher Edition, page 234).
  - Lesson 12: "Say, Now that we have a way of comparing the different fuel choices for future space missions. Lets[sic] apply this tool in a personal evaluation for nuclear and

hydrogen rockets. Once the class has built a consensus around the ranking of the criteria and constraints, have students return to their table groups" (Teacher Edition, page 272).
    - Lesson 15: "State the transportation goal you chose to focus on. Describe the transportation option(s) you chose to meet this goal" (Lesson 15 Handout Final Design Proposal).
- *Changes in systems may have various causes that may not have equal effects.*
    - Lesson 13: "Directions: Things to consider: Does the energy source of your transportation solution meet the energy supplied in the conventional method? How might the engineering approach (avoid, improve, shift) impact CO emissions? Consider Figure 2: CO Emissions by Mode of Transportation and the mode of transportation your solution is addressing. What size impact would you expect your transportation solution to have on CO emissions between 2020–2030?" (C.5 Lesson 13 Handout Utilizing Decision Matrix, page 2). When students use the decision matrix, students "estimate the size of effect for accessing, or implementing those solutions" (Teacher Edition, page 284). They also consider this CCC when using the STAMP Protocol. It is not clear that students use this element since students are comparing different (single) causes rather than comparing the differing effects of multiple causes acting at the same time.

Scale, Proportion, and Quantity

- *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
    - Lesson 7: "Revise the following claim to reflect a more supported claim. Diesel transfers more energy because weaker bonds are breaking and stronger bonds are forming. Diesel transfers more energy because more stronger bonds are formed than gasoline" (Teacher Edition, page 170). It is not evident how the task on page 170 involves a use of this element and connections to this element are weak based on the verbiage. Students do not show understanding of various levels of significance of phenomena.

Energy and Matter: Flows, Cycles, and Conservation

- *The total amount of energy and matter in closed systems is conserved.*
    - Lesson 6: "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?" (C.5 Lesson 6 Handout Modeling Energy Changes).
    - Lesson 7: "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? It gained energy because more energy went in then came out" (Teacher Edition, page 171). This activity is better aligned with CCC **5.2** or CCC **5.3** since it deals with energy moving in and out of a system.
    - Lesson 8: Students balance chemical reactions. "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 Calculating Carbon Emissions in pairs… 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 tracing of molecular transformations. Encourage students to use matter and energy in their reasoning" (Teacher Edition, page 187). "2. Write and balance the chemical equation for the reaction of your chosen fuel with oxygen gas to produce water vapor and carbon dioxide. 3. How can you use the balanced equation to determine how many moles of carbon dioxide are produced when one mole of your fuel combusts? 4. Calculate the mass of carbon dioxide produced when one gallon of fuel is burned. This will create a conversion factor you can use in the next question. The molar mass of carbon dioxide is 44.01 g/mol" (Lesson 8 Handout Calculating Carbon Emissions, page 1). Students focus on matter conservation; for this particular prompt it is not clear that students need to use an understanding that energy is also conserved, although that understanding is engaged elsewhere in the lesson.

- *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.*
  - Lesson 1: The fuel data cards include information about the inputs and outputs of each example fuel. The inputs include where the matter comes from (e.g., crude oil) and what the matter outputs are (e.g., CO_2 released). Similarly, the energy released is listed as an output (C.5 L1 Fuel Data Cards).
  - Lesson 2: "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" (Teacher Edition, page 67).
  - Lesson 4: "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 3's kinetic energy was higher before the collision. If students modeled the bond breaking: Atom 1 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 Atom 1 wobbled back and forth" (Teacher Edition, page 115).
  - Lesson 5: "Have the M-E-F poster available for students to view as they develop their 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)" (Teacher Edition, page 132).

- Lesson 6: "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" (Teacher Edition, page 155).
- Lesson 8: "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" (C.5 Lesson 8 Assessment Cold Pack Assessment, page 4). This performance is better aligned with CCC **5.3** since it is specific to energy conservation as it flows in and out of fields.
- Lesson 15: Students develop a design proposal for a transportation system. "Explain how your chosen option(s) transfer 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" (Lesson 15 Handout Final Design Proposal).

● *Energy cannot be created or destroyed — only moves between one place and another place, between objects and/or fields, or between systems.*
  - Lesson 1: "Develop an initial model to explain how a fuel is used to provide energy to make a vehicle move" (C.5 Lesson 1 Slides, Slide J). The CCC is cited as students create initial models, but there is not specific guidance related to this element.
  - Lesson 5: "Text Chunk 1: Where does the energy in fossil fuels and biofuels come from?" (C.5 Handout Comparing Fuels, page 2). This question elicits students understanding that energy moves between places, objects, fields, and systems, but not that it cannot be created or destroyed.

● *In nuclear processes, atoms and not conserved, but the total number of protons plus neutrons is conserved.*
  - Lesson 11: "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" (Teacher Edition, page 250).

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.*
  - Lesson 2: "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)" (Teacher Edition, page 63). It is the teacher who develops an understanding of this element in this lesson. Students examine the properties of gasoline, but they are not prompted to consider the properties of other materials in the engine or to understand that they need to consider all of these properties and structures in order to reveal its function.
  - Lesson 11: "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... 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" (Teacher Edition, page 248). However, there is no discussion of the properties of the materials.

Suggestions for Improvement

Science and Engineering Practices

- In the Assessment Opportunities where SEP elements are cited, consider using terms like "working toward" if the element will be more fully developed later in the unit, and something like "fully using" where the element is expected to be fully developed.

- Consider ensuring that focal elements are developed rather than only used.
- Consider eliminating claims of elements that students do not actually use.

Disciplinary Core Ideas

- Consider creating additional tasks in which students would authentically need to use the content contained in the ESS elements.
- Consider eliminating claims of elements that students do not actually use.

Crosscutting Concepts

- Consider making CCC ideas explicit to students as sense-making tools that could be applied again in new situations.
- Consider ensuring that focal elements are developed, rather than only used.
- Consider eliminating claims of elements that students do not actually use.

I.C. INTEGRATING THE THREE DIMENSIONS

Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.

Rating for Criterion I.C. Integrating the Three Dimensions	Extensive

The reviewers found extensive evidence that student performances integrate elements of the three dimensions in service of figuring out phenomena or designing solutions to problems. Several tasks require the use of all three dimensions to make sense of the phenomenon or to develop a solution to a problem. The use of targeted SEP and CCC elements are sometimes necessary for students to understand the DCIs. However, some performances only use one dimension at the high school level.

Related evidence includes:

- Lesson 3: 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**) Students use the following elements:
    - SEP: *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.* The class constructs a model based on several investigations and then analyzes new CODAP data and makes additions to the model.

   - DCI: *At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.* Students notice that changes in volume and pressure of air affect the temperature.
   - CCC: *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.* Students consider cause and effect when discussing the transfer of energy to the air.
- Lesson 4: 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**)
   - SEP: *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.* Students discuss how new data affects understanding of the cylinder system.
   - DCI: *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.~~* Students use a physical model to show how energy is transferred in a system when objects collide. Although students see that bonds can be broken, it is unclear that they understand that rearrangement of atoms into new molecules.
   - CCC: *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 class maps energy transfer in a model.
- Lesson 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**)
   - SEP: *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.* Students use a simulation model and a physical model that both show the movement of matter and energy into and out of a system
   - DCI: *When two objects interacting through a field change relative position, the energy stored in the field is changed.* Students observe that there is a change in the energy in the marble system when a bond forms.
   - CCC: *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.* Students observe the marble model and discuss the transfer of energy when a bond forms.
- Lesson 7: 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**)
   - SEP: *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. Students provide a critique of an explanation about the amount of energy being transferred out of a reaction using evidence from their investigation.
    - DCI: *When two objects interacting through a field change relative position, the energy stored in the field is changed.* The class discusses the transfer of energy when gasoline combusts, noting that energy is transferring out when bonds are broken.
    - CCC: *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.* Students consider the particle level to explain about bond strengths and energy transfer.
- Lesson 8: 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**) Students may only be using one dimension at the high school level:
    - SEP: *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.* Students make use of a mathematical model to calculate the CO_2 produced in a combustion reaction.
    - DCI: ~~*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.* The class discusses current and future use of fuels in transportation. There is no discussion of altering the size of human populations or driving human migrations.
    - CCC: *The total amount of energy and matter in closed systems is conserved.* Students write a balanced equation to calculate carbon dioxide emissions, showing that matter is conserved. It is not clear that students understand that energy is also conserved.
- Lesson 11: 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**) Students use two dimensions together:
    - SEP: *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.* Students complete a reading selection and a simulation to refine their explanation of energy transfer.
    - DCI: *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.* Students conclude that the total number of protons and neutrons in the reactants is equal to the total number in the products.
    - CCC: *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.* Students discuss how parts or interactions made sense in terms of how they might work together to make the vehicle move. However, there is no discussion of the properties of the materials.

Suggestions for Improvement

Applying suggestions listed under Criterion I.B would help strengthen the evidence for this criterion.

I.D. UNIT COHERENCE

Lessons fit together to target a set of performance expectations.

i. Each lesson builds on prior lessons by addressing questions raised in those lessons, cultivating new questions that build on what students figured out, or cultivating new questions from related phenomena, problems, and prior student experiences.

ii. The lessons help students develop toward proficiency in a targeted set of performance expectations.

Rating for Criterion I.D. Unit Coherence	Extensive

The reviewers found extensive evidence that lessons fit together coherently to target a set of PEs. Similar SEPs, CCCs, and DCIs are grouped together within lesson sets that help the student with sense-making within that lesson set. The learning is coherent to students and each lesson focuses on answering student generated questions, which is highlighted through "navigation" steps at the beginning of each lesson.

Each lesson begins with a "navigation" step that recaps the main learning from the previous lesson and highlights a question that is not yet answered. Answering that question is the focus of the lesson. Related evidence includes:

- Lesson 2: "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. 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" (Teacher Edition, pages 62–63).
- Lesson 3: "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….What is still unclear about diesel engines in particular? We don't really know why the compression causes combustion" (Teacher Edition, page 91).
- Lesson 4: "What have we figured out so far about gasoline, diesel, and other carbon-based fuels? How different kinds of engines work. Where the CO 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?" (Teacher Edition, page 106).

- Lesson 6: "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" (Teacher Edition, page 150).
- Lesson 7: "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" (Teacher Edition, page 162).
- Lesson 8: "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" (Teacher Edition, page 179).
- Lesson 9: "Give students a moment to reflect on Our DQB Questions and then discuss the prompts as a class. What do we want to know more about?" (Teacher Edition, page 203).
- Lesson 10: "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" (Teacher Edition, page 231).
- Lesson 12: "Have students call back to their learning [from the previous lesson]…What were the benefits and risks of using uranium as a fuel source?" (Teacher Edition, page 269).
- Lesson 13: "Leverage student questions to suggest that the class 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 as a whole. 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" (Teacher Edition, page 279).
- Lesson 14: "Turn and talk with a partner about the last class. Present 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." (Teacher Edition, page 294).
- Lesson 15: "Navigate. Display slide A and have students take out [sic] Transportation Arguments Draft from last class. Give students five minutes to discuss the feedback they have received on their chosen transportation goal or solution from the previous lesson. Each student should spend about a minute summarizing their ideas and feedback they have received from peers in Lesson 14. Then they should plan how to edit their proposals using this feedback" (Teacher Edition, page 311).

Similar elements of the three dimensions are grouped together within a section of the unit. For example, in Lesson Set 1, students use models to develop understanding of matter and energy conservation. In Lesson Set 3, students use arguments to develop understanding of the relationship between the Earth and human activity. This helps with unit coherence as students immediately see how their learning is building within a lesson set but may limit the transferability of these elements to other domains (see I.E for related evidence).

The materials claim that the unit builds toward multiple PEs (Teacher Edition, page 17). The majority are claimed to be developed across multiple courses or multiple units. The stated learning targets are listed on page 17 of the Teacher Edition.

- **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 PE is developed across multiple units.
†This PE is developed across multiple courses.

Only one PE (**HS-PS1-4**) is claimed to solely be built towards in this unit. **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.* Related evidence for developing proficiency in this unit includes:

- Lesson 4: "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)" (Teacher Edition, page 105).

- Lesson 5: Students use two simulations to investigate bond breaking and forming (Teacher Edition, pages 151–152). "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" (Teacher Edition, page 153).
- Lesson 6 "Develop models in pairs. Present slide F. Help students start the model by drawing the substances involved in the reaction. Highlight to students how you can represent gasoline by just showing 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" (Teacher Edition, page 182). They then share their models with another pair before creating a detailed class consensus model of the reaction.
- Lesson 8: The hot/cold pack assessment has students using this Performance Expectation (PE). "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; CCC: 5.2; DCI: PS1.A.4, PS1.B.1)" (Teacher Edition, page 377).

Suggestions for Improvement

Consider providing teachers with guidance for what to do if students do not supply the ideal answer that would drive their perception of unit coherence, such as batteries in Lesson 9.

I.E. MULTIPLE SCIENCE DOMAINS

When appropriate, links are made across the science domains of life science, physical science and Earth and space science.

i. Disciplinary core ideas from different disciplines are used together to explain phenomena.

ii. The usefulness of crosscutting concepts to make sense of phenomena or design solutions to problems across science domains is highlighted.

Rating for Criterion I.E. Multiple Science Domains	Adequate

The reviewers found adequate evidence that links are made across the science domains when appropriate. Physical science and Earth and space science ideas are required to fully explain the unit phenomenon. There are few examples of lessons in which PS and ESS DCIs are used together, although most physical science DCIs are grouped in Lesson Set 1, while most ESS DCIs are grouped in Lesson Sets 2 and 3. Earth science topics are not emphasized enough to allow students to come to a full understanding of how different DCI ideas can be used together to explain phenomena. CCC elements are used in the unit, but the use of CCCs to make explicit connections between domains is not evident

The instance when PS and ESS DCIs are integrated within a LLPE occurs in Lesson 1: "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)" (Teacher Edition, page 326). In this lesson students integrate ideas from the engine with the fuel cards and how other fuels have been developed that produce less pollution.

Examples of LLPEs containing only physical science DCIs are found in Lesson Set 1, including:

- Lesson 4: "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)" (Teacher Edition, page 328).
- 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)" (Teacher Edition, page 329).
- 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)" (Teacher Edition, page 330).
- Lesson 8: "8.A Develop a model based on evidence to illustrate energy transfer in or out of a chemical reaction system depending on energy transfer in and out of fields as particular bonds break and form. (SEP: 2.3; DCI: PS1.A.4, PS1.B.1; CCC: 5.2)" (Teacher Edition, page 331).

Examples of LLPEs containing only Earth and space science DCIs are found in Lesson Sets 2 and 3. However, in some of these lessons (9, 10, 15), students need to also use previously learned PS content. As an example, in Lesson 10, students would need their knowledge of how greenhouse gases are produced. However, students are not always made aware that they are using PS together with ESS. ESS LLPEs include:

- 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)" (Teacher Edition, page 331).
- Lesson 10: "10.A Analyze data about greenhouse gases 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)" (Teacher Edition, page 332).

- Lesson 11: "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)" (Teacher Edition, page 333).
- 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)" (Teacher Edition, page 334).
- Lesson 14: "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)" (Teacher Edition, page 334).
- 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)" (Teacher Edition, page 335).

There are missed opportunities for CCC usefulness across domains. Some examples include:

- The M-E-F Poster is used in the unit and prior units. There are missed opportunities to connect prior learning with CCCs related to the M-E-F poster.
- Lesson 1: Students sort the cards and use the CCC of **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)" (Teacher Edition, page 42). There is not a connection to how the CCC **1.3** is used across multiple domains.
- Lesson 2: Students consider structure and function regarding vehicle parts. "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)" (Teacher Edition, page 63). There is a missed opportunity to connect the CCC to students' prior learning about structure and function.
- Lesson 14: "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" (Teacher Edition, page 296). This is a missed opportunity to link the CCC to other domains.

Suggestions for Improvement

- Since this is the last unit of the chemistry course, consider making connections to how the CCCs were used across domains in the other chemistry units such as referencing a connection made to life or Earth science in a previous chemistry unit.
- Consider adding callouts when CCCs are used to prompt teachers to help students connect with other contexts in which they have used that CCC element in the past.

I.F. MATH AND ELA	
Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.	
Rating for Criterion I.F. Math and ELA	Extensive

The reviewers found extensive evidence that the materials provide grade-appropriate connections to the Common Core State Standards (CCSS) in mathematics, English language arts (ELA), history, social studies, or technical standards. Notes are provided about connections to the CCSS, but these notes are teacher facing, so students may not be aware of the connections. In addition to specific CCSS being claimed and used by the students, there are multiple opportunities for students to speak and listen to their peers and they are provided with diverse and varied reading materials within the unit.

ELA standards are cited in the lessons. Students also have the chance to use multiple types of resources in the unit to read and gather information from. Related evidence includes:

- **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.*
    - Lesson 2: 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 (Teacher Edition, page 86).
    - Lesson 8: Students synthesize information from the class consensus model, Potassium Chloride or Calcium Chloride and Water 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 (Teacher Edition, page 194).
    - Lesson 10: "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" (Teacher Edition, page 240).
    - Lesson 10: 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 (Teacher Edition, page 263).
- **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.*
    - Lesson 5: Students use text to compare fuels, as well as the advantages and disadvantages of different fuels (Teacher Edition, page 144).
    - Lesson 10: 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 (Teacher Edition, page 263).
- **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.*
    - Lesson 9: Students use text to compare the advantages and disadvantages of using batteries and electric vehicles as a future transportation option (Teacher Edition, page 225).
- **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 (Teacher Edition, page 263).
- **CSS.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.*
    - Lesson 12: In writing, students compare arguments for different rocket fuels, drawing on evidence from texts (Teacher Edition, page 273).
- **CCSS.ELA-LITERACY.WHST.9-10.9**: *Draw evidence from informational texts to support analysis, ~~reflection, and research.~~*
    - Lesson 12: In writing, students compare arguments for different rocket fuels, drawing on evidence from texts (Teacher Edition, page 273).
    - Lesson 13: Students use evidence from fuel data cards and two readings to support arguments for adding subcategories for evaluation of criteria and constraints on the Consensus Decision Matrix (Teacher Edition, page 287).
- **CCSS.ELA - WHST.9-10.1** *Write arguments focused on discipline-specific content. In writing, students compare arguments for different rocket fuels, drawing on evidence from text.*

- Lesson 12: In writing, students compare arguments for different rocket fuels, drawing on evidence from texts (Teacher Edition, page 273).

- **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.*
    - Lesson 14: Students develop individual claims about which fuels they think would be the best fuels to use with future vehicles. 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 (Teacher Edition, page 305).
    - Lesson 15: 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 (Teacher Edition, page 315).
- Students have multiple sources to read and synthesize information from during the course of the unit. A few examples include:
    - Lesson 5: In Comparing Fuels, students read an article adapted from various sources (Lesson 5, Comparing Fuels Handout).
    - Lesson 9: The Point and Counterpoint: Addressing Accessibility and Point and Counterpoint: Addressing Environment handouts all have various news or journal articles cited that the articles are adapted from.
    - Lesson 10: The Infrastructure: Nuclear Plants handout has various news or journal articles cited that the articles are adapted from.
    - Lesson 11: Many of the readings in this lesson are adapted from various news or journal articles cited.

Mathematics standards are cited in the lessons. There is also a section in the Teacher Background Information that is titled "What mathematics concepts will students engage with in the unit". Related evidence includes:

- Teacher Background Information: "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 [sic] Polar Ice Unit (unit conversions), [sic] Space Survival Unit (balancing chemical equations), and [sic] 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 [sic] Polar Ice Unit" (Teacher Edition, page 27).
- **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.~~*

- Lesson 2: 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 (Teacher Edition, page 86). This performance is not well aligned with this standard, because coefficients are not commonly considered a type of unit.
- Lesson 7: 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 in and out of the system, and then the net energy transfer. Students must consider multiple units including the number of bonds and bond energy (Teacher Edition, page 171).
- Lesson 8: Students work to quantify and scale up energy transfer and carbon dioxide emissions as a result of the combustion of gasoline on the Combustion of Methane. They use unit conversions to move between grams, moles, and kJ. The teacher then walks through how to move between grams of gasoline, to kilograms and then convert to kilograms of carbon dioxide (Teacher Edition, page 195).

Students have opportunities for speaking and listening to peers in a variety of formats and scenarios. Related evidence includes:

- Lesson 1: "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" (Teacher Edition, page 41).
- Lesson 3: "Show slide B and use the images and text on the slide to review three phenomena from Lesson 2. 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 students have time to discuss the prompts, display slide D and bring the class together for a quick sharing of ideas" (Teacher Edition, page 91).
- Lesson 7: "Engage in argument about the results. Display slide H. 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 partner during the investigation from the last lesson step. Use the prompts below to lead a whole class discussion. As students share, give them opportunities to respond to and counter each others' claims using evidence. Consider allowing students to write their ideas before sharing if time allows" (Teacher Edition, page 165).
- Lesson 14: "Explain the Stand Up-Hand Up-Pair Up protocol. Present slide X. Talk through the slide to explain the protocol students will use to share their arguments. Explain that they will have 6 minutes in each pair; 1 minute for person 1 to share their ratings, 1 minute for person 2 to repeat ideas and ask questions, and 1 minute for person 1 to respond to person 2" (Teacher Edition, page 302).

Suggestions for Improvement

- Consider adding support for teachers to highlight to students when they are engaged in interdisciplinary learning.
- Consider eliminating the mathematics connection in Lesson 2 or identify a standard that more closely matches the student activity.
- Consider referencing the strategies for reading found in the general Teacher Handbook in specific lessons where those strategies would be useful to better align and support students with the ELA standard.

OVERALL CATEGORY I SCORE: **2** (0, 1, 2, 3)	
Unit Scoring Guide – Category I	
Criteria A-F	
3	At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C
2	At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C
1	Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C
0	Inadequate (or no) evidence to meet any criteria in Category I (A–F)

CATEGORY II

NGSS INSTRUCTIONAL SUPPORTS

II.A. RELEVANCE AND AUTHENTICITY

II.B. STUDENT IDEAS

II.C. BUILDING PROGRESSIONS

II.D. SCIENTIFIC ACCURACY

II.E. DIFFERENTIATED INSTRUCTION

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

II.A. RELEVANCE AND AUTHENTICITY

Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world.

i. Students experience phenomena or design problems as directly as possible (firsthand or through media representations).

ii. Includes suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate.

iii. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to questions from their own experience.

Rating for Criterion II.A. Relevance and Authenticity	Extensive

The reviewers found extensive evidence that the materials engage students in authentic and meaningful scenarios that reflect the real world. In this unit, students have opportunities to experience phenomena and problems as directly as possible. There are also suggestions for how to connect instruction to the students' homes, neighborhoods, communities, or cultures. However, some of the most impactful experiences are considered to be alternate or extensions, so it is less likely that all students would have the opportunity to complete them. There are opportunities for students to connect their questions and prior experiences to the explanations they are building and the solutions they are designing.

Students experience the phenomena or design problems as directly as possible. Related evidence includes:

- Lesson 1: "CONSIDER CAUSES OF CO_2 EMISSION CHANGES Have students turn and talk with a partner to analyze a graph of past CO emissions data" (Teacher Edition, page 36).
- Lesson 1: "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" (Teacher Edition, page 36).
- Lesson 1: "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" (Teacher Edition, page 36).
- Lesson 2: Students see images, videos, and demos to help them gather information about combustion engines. "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" (Teacher Edition, page 64). "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 [sic] Gasoline Engine Operation" (Teacher Edition, page 65). Students observe combustion demonstrations. "Test what happens when we add a spark to a fuel in a clear cylinder…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" (Teacher Edition, pages 67–69).

- Lesson 6: Students use a simulation to investigate bond breaking and formation. "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 3A is also adjustable" (Teacher Edition, page 151). Limitations of the model are considered. "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" (Teacher Edition, page 151).
- Lesson 8: Students complete investigations alongside readings for the transfer tasks of the hot packs and cold packs. "Students will investigate a reaction that powers hot and cold packs. By seeing this reaction's dramatic temperature change with their own eyes, they will have deeper motivation for figuring out the reaction's components in the assessment task" (Teacher Edition, page 192).
- Lesson 9: Students observe and use a voltmeter to learn more about batteries. "O. Hold up the voltmeter/ammeter and turn it on. Say, This device has been modified so it can also measure voltage. To use it as a voltmeter, you will make use of the new yellow connection wire in combination with the red 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" (Teacher Edition, page 211).
- Lesson 10: Students utilize gas data from Earth's atmosphere. "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" (Teacher Edition, page 235).
- Lesson 12: This lesson connects to prior learning about using nuclear fission to power transportation. There is guidance for the teacher to navigate to the lesson. "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 board with a partner…If students do not suggest space travel as an option, draw on their benefits and risks to elicit ideas about applications that are not near people and 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)" (Teacher Edition, page 269). This line of questioning is unlikely to be authentically motivating to students.

There are suggestions for how to connect instruction to the students' interests, homes, neighborhoods, communities, and/or cultures. Related evidence includes:

- The context of the unit is likely to be relevant to high school-aged students. For example:
    - "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 'How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?' was 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?'" (Teacher Edition, page 13).
    - Lesson 2: "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" (Teacher Edition, page 64).
- Teacher Background Knowledge: There are ideas for extensions or enhancing the unit that connect to student lives. "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 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" (Teacher Edition, page 27). These experiences are both considered "extensions/enhancements," so not all students would have the opportunity to experience these connections.

- Teacher Background Materials: There is a home communication letter that provides support for conversations and having students make sense of their learning when students talk about the unit with their families (Teacher Edition, page 33).
- Lesson 1: There is a note that some fuel sources can be included if steam-operated devices are of interest to the students. "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" (Teacher Edition, page 38).
- Lesson 1: "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" (Teacher Edition, page 50). "Discuss these questions with a trusted member of your community or family: ● How and when do you travel? Why do you travel? ● What would make a fuel more desirable for that use? ● What would your ideal transportation system be? How would that affect the fuel that is used?" (Lesson 1 Slides, Slide W).
- 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" (Teacher Edition, page 41).
- Lesson 1: There is a note about highlighting the prior knowledge of students who know more about engines. "Some students may be involved in engine repair classes and this is a great opportunity to capture their ideas" (Teacher Edition, page 47).
- Lesson 2: "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" (Teacher Edition, page 64).
- Lesson 1: Students talk with a trusted member of the community about what criteria they think are important when considering fuels and transportation. "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" (Teacher Edition, page 50).

- Lesson 1: There is an extension opportunity to look more closely at the history of transportation in the students' area. "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" (Teacher Edition, page 51). This is an alternate activity, so not all students would have the opportunity to experience this.
- Lesson 14: Students are encouraged to get feedback from a trusted adult. "Introduce the need for additional feedback from a trusted adult to motivate Home Learning. Present 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 and receive their feedback on it as well. Emphasize that sharing and getting additional feedback from a trusted adult can help students refine their ideas in preparation for the next lesson" (Teacher Edition, page 304).
- Lesson 15: There is an alternate activity suggestion. "If you feel students have already fully fleshed out their thinking around their own design proposals, you may instead ask them to apply the design matrix to a current proposal for transportation in their community or region" (Teacher Edition, page 311). This is an alternate activity, so not all students would have the opportunity to experience this.

The unit provides opportunities to connect students' explanations or design solutions to questions from their own experience. For example:

- Lesson 1: Students connect their initial ideas and questions to their own experiences from previous OpenSciEd units. "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 [sic] Polar Ice Unit and [sic] Space Survival Unit, and a lot in [sic] Oysters Unit when we were defining the problem and proposing possible solutions. Place a pile of green and blue sticky dots next to the Driving Question Board. 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" (Teacher Edition, pages 51–52).
- Lesson 2: Students are asked what they wonder about gasoline, which drives looking into an explanation to add to their current models. "What do these differences make you wonder about the prevalent use of gasoline in personal vehicles?...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" (Teacher Edition, page 62).

- Lesson 7: Students are prompted to consider their past experiences from the Space Survival unit. This problematizes the need to look at modeling the interactions. "Display slide E, and say In [sic] 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 [sic] Space Survival Unit that bonds are different from one another, but we have not reflected on this in a while. Have the students share what they remember from that unit. Ask students to briefly discuss the prompts on the slide" (Teacher Edition, page 163).
- Lesson 9: "Consider the different batteries you have encountered in your experiences. What makes a battery 'good' for any given use?" (Teacher Edition, page 207). Students are encouraged to consider the model and the DQB to then consider batteries and electric vehicles. "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 from our Driving Question Board. Give students a moment to reflect on Our DQB Questions and then discuss the prompts as a class…What do we want to know more about?...Out of the non-carbon based fuels mentioned on the DQB, which do we have the most firsthand experience with?...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" (Teacher Edition, page 203).

Suggestions for Improvement

- Consider incorporating more of the connections to students' lives as part of the lessons as opposed to being framed as "alternate/extension" activities so that more students have the opportunity to see connections between the unit and their experiences.
- Consider using video and other kinds of media to provide more motivation for student engagement.

II.B. STUDENT IDEAS

Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate.

Rating for Criterion II.B. Student Ideas	Extensive

The reviewers found extensive evidence that the materials provide students with opportunities to both share their ideas and thinking and respond to feedback on their ideas because there are multiple opportunities to elicit student ideas and for students to respond to feedback. Throughout the unit there is guidance to help draw out student ideas and have students justify, clarify, and explain their thinking. Many whole-class discussions have specific guidance to help the teacher draw out student ideas. Students have opportunities to revise their thinking based on feedback.

Students have opportunities to express, clarify, justify, interpret, and represent their ideas throughout the unit. Some examples include:

- Lesson 1: Students have the opportunity to verbally express initial ideas and connections to previous units with a partner and in a whole-class discussion. "Have students discuss what they notice and wonder about the graph with a partner for two minutes…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" (Teacher Edition, page 40). Later in the lesson there is guidance for the teacher on how to help facilitate a conversation as they brainstorm criteria and constraints. "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" (Teacher Edition, page 49).
- Lesson 2: There is guidance to help the teacher ensure students are considering their partner's ideas when thinking about the consensus model. "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?'" (Teacher Edition, page 63). Later in the lesson, there is a building understanding discussion about fuel comparisons. There is guidance to help the teacher facilitate this discussion through prompts and a call out. "Use the following prompts to guide the class in sharing their responses to the questions on Fuel Data Comparisons… 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" (Teacher Edition, page 83).

- Lesson 4: In the lesson students justify their thinking. "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" (Teacher Edition, page 111). Students complete a written comparison of two models. (Lesson 4 Handout Mapping Between Models).
- Lesson 5: "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" (Teacher Edition, page 142). A sample of what students may write is included.
- Lesson 8: Students reflect on answered questions from the DQB in a Scientists Circle. There is guidance for the teacher to help facilitate this discussion. "Purpose of this discussion: To come to consensus about the questions we think we have answered, left unanswered, or have questions about. To prepare for the upcoming assessment by discussing what the answers are 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 the class this in the beginning as well. Say that you might invite others who have not yet contributed to the conversation…Do not just tell students the answers. If disagreeing ideas emerge, or students indicate confusion, do not tell the correct response. Rather, set up the disagreement, say, 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 discussing until the whole class either has come to consensus or has agreed to disagree until we gain more information" (Teacher Edition, page 190).
- Lesson 11: Students read and complete a jigsaw activity about different aspects of nuclear fission. "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 most main idea from their reading and 2–3 supporting details" (Teacher Edition, page 260).
- Lesson 12: Students argue their fuel choice. They compare arguments for possible rocket fuels and utilize the class-generated criteria and constraints. "Students argue their fuel choice using evidence. Display slide H, pass out [sic] Rocket Fuel Argument, and tell the students that they will now be arguing which fuel choice, if any, meets the needed criteria and constraints for an optimal rocket fuel. Students' argument[sic] should begin by defining the problem this fuel choice is looking to overcome, followed by which, if any, fuel they would recommend for our Mars missions, and their rationale for this choice" (Teacher Edition, page 273).

Students have opportunities to respond to feedback and revise their thinking. Students have some structured opportunities to reflect on feedback to their ideas

- Lesson 1: After students complete their initial models at the end of Day 1, Day 2 starts with students sharing their models with a peer after reviewing community agreements and allowing time to revise their models. “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” (Teacher Edition, page 45).
- Lesson 2: Students have a chance to revise their thinking after learning more about engines. “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 [sic] Initial Fuel Model. As you work, start with matter, then energy, then forces. Have the M-E-F poster from [sic] 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 [sic] 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” (Teacher Edition, page 66). After the discussion, they add to their models again. “After the discussion, give students two minutes to add any new ideas to their initial models” (Teacher Edition, page 67).
- Lesson 4: “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” (Teacher Edition, page 109).
- Lesson 5: “Present 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 2-3 minutes, use the prompts below to lead a discussion” (Teacher Edition, page 134). Students then test their predictions and ideas with a simulation. “Examine the data tables students developed to ensure the way they are organized will support students in using the data to evaluate their predictive models” (Teacher Edition, page 134). Later in the lesson they revise the initial class model from Lesson 1 using their new information. “Tell students that they will use their explanations and feedback to help update the initial class consensus model, and to be prepared to share the ideas they see and hear during conversations with their partners during the upcoming class discussion. Tell students to spend about a minute each explaining their explanation to their partner, and then spend the next two minutes giving each other feedback…We have figured out a lot about what happens when fuels combust and how energy changes. Suggest taking a moment to update the consensus model from Lesson 1. Have the initial consensus model visible in the room for students to reference” (Teacher Edition, page 139). “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, in addition to 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 and routines and more tools for peer assessment may be found in the OpenSciEd Teacher Handbook: High School Science" (Teacher Edition, page 139).

- Lesson 6: Students discuss and model energy transfers. The lesson suggests strategies to have the students engage in conversation and revise their thinking. "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. 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" (Teacher Edition, page 155).
- Lesson 7: "Display slide H. 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 partner during the investigation from the last lesson step. Use the prompts below to lead a whole class discussion. As students share, give them opportunities to respond to and counter each others' claims using evidence. Consider allowing students to write their ideas before sharing if time allows" (Teacher Edition, page 165). After this activity there is an "alternate activity" where they can reflect on the feedback they gave. "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" (Teacher Edition, page 167).
- Lesson 9: Students use a Scientists Circle to compare the points and counterpoints of electric vehicles. "Direct students to choose only one of the four to evaluate, as they will hear from other students with different arguments during the following Scientists Circle. Encourage them to pick an argument that surprises them or might differ from their current thinking. Give them 8 minutes to read and annotate their chosen handout…. 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 kind[sic] of discussions include: What can we conclude? How did you arrive at that conclusion? What is your evidence? Does any group have evidence to support Student A's argument? What data do we have that challenges Student B's argument?" (Teacher Edition, pages 203–204). There is also guidance on how to use a Discussion Mapping Tool for this discussion.
- Lesson 11: "Consider collecting students' Progress Tracker[sic] and give feedback around how students incorporated thinking about unanticipated effects with the associated costs as we seek to design improved systems" (Teacher Edition, page 262).

- Lesson 13: Students develop categories and subcategories for the criteria/constraint grouping that is most relevant to their transportation solution. There is guidance to help the teacher provide feedback with questioning so the students can respond to the feedback. “Ensure that students are using evidence and data from the fuel data cards and transportation solution and drawback readings to develop arguments for the subcategories they will suggest be included in the Consensus Decision Matrix. Prompt students to clarify what evidence they are using and the source they used. (SEP: 7.4)... After five minutes, pair groups together to form larger groups. Each small group should share the subcategories and reasons for including them. Then as a larger group they 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 [sic] 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” (Teacher Edition, page 285).
- Lesson 14: Students share arguments then revise them from feedback. “Explain the Stand Up-Hand Up-Pair Up protocol. Present slide X. Talk through the slide to explain the protocol students will use to share their arguments. Explain that they will have 6 minutes in each pair; 1 minute for person 1 to share their ratings, 1 minute for person 2 to repeat ideas and ask questions, and 1 minute for person 1 to respond to person 2. Ask students if they have any clarifying questions before starting the activity. Have a 1 minute timer for students to help them keep on track with their timing. Have students repeat this two more times so they meet with a total of 3 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 [sic] STAMP Assessment Guidance when they turn in [sic] 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…Consult with small groups on feedback received during the Stand up-Hand up-Pair up protocol. Present slide Y. Have students consider the prompt on the slide and discuss in their groups for about 5 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. Present slide Z. Give students about 7 minutes to complete parts 2 and 3 of [sic] Transportation Arguments Draft which ask students to revise their arguments. ✱ 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 [sic] Transportation Arguments Draft. As students work to complete parts 2 and 3 of [sic] Transportation Arguments Draft, conduct the STAMP Protocol check for this lesson using [sic] STAMP Protocol Matrix” (Teacher Edition, pages 302–303).

Suggestions for Improvement

- Consider adding additional opportunities for formal peer feedback.
- Consider adding additional opportunities for students to reflect on and respond to formal feedback from their teacher or peer.

II.C. BUILDING PROGRESSIONS

Identifies and builds on students' prior learning in all three dimensions, including providing the following support to teachers:

i. Explicitly identifying prior student learning expected for all three dimensions

ii. Clearly explaining how the prior learning will be built upon.

Rating for Criterion II.C. Building Progressions	Extensive

The reviewers found extensive evidence that the materials identify and build on students' prior learning in all three dimensions. The unit front matter outlines expected prior knowledge and possible alternative conceptions students might have, and each lesson is preceded by a description of which elements of each dimension will be used in the lesson. There is evidence related to all three dimensions, but the unit places more emphasis on DCIs when discussing progressions.

The teacher materials outline expected prior knowledge and possible alternative conceptions that students will have at the start of the unit. For example:

- On pages 21–24, the materials list the DCIs from a middle school science program that should have been previously developed.
- On pages 21–24, the materials list DCIs previously developed in other high school biology, physics, and chemistry classes.
- Teacher Background Materials: There is a section titled "What are some common ideas that students might have?" that highlights some common prior knowledge and potential connections for the unit to student's experiences (Teacher Edition, page 26). "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. 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 force from their hands to break a 'bonded' magnet pair" (Teacher Edition, page 26).

- Previous learning in SEPs and CCCs is shown in a table, but does not include specific elements (Teacher Edition, page 25).
- There is a specific callout for the M-E-F poster and its use across multiple units as students use and develop elements related to matter, energy, and forces. "The M-E-F (matter-energy-forces) poster was built by students starting in [sic] 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" (Teacher Edition, page 24).

There is guidance to help the teacher pull out prior learning or support prerequisite understandings. For example:

- Lesson 2: "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 [sic] 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" (Teacher Edition, page 79).
- Lesson 5: "Students' prior work with energy conservation thinking has included tracking energy in Earth systems in [sic] 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 [sic] Electrostatics Unit, where students used a simulation to see that the kinetic 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" (Teacher Edition, pages 152–153).

- Lesson 11: "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" (Teacher Edition, page 249).
- Lesson 7: "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 paperclip model from [sic] Electrostatics Unit and [sic] Space Survival Unit in which electrons do repel, but also are attracted to the nuclei of both their own atom and a bonded atom" (Teacher Edition, page 165).
- Lesson 9: "It is important that students have some experience with ionic compounds and electrolytes from [sic] Electrostatics Unit and [sic] Space Survival Unit. Refer back to what students figured out during these units to help them build on this prior knowledge" (Teacher Edition, page 216).

Each lesson includes a "where we are going" section that describes the targeted three dimensions used in the lesson. While all three dimensions are discussed at some point in the unit, more emphasis is placed on development of DCIs, whereas development (as opposed to use) of SEPs and CCCs is rarely discussed. Some examples include:

- Lesson 2: "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 [sic] 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 [sic] Polar Ice Unit and [sic] 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 [sic] Polar Ice Unit and [sic] 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)" (Teacher Edition, page 61).
- Lesson 4: "This lesson is designed to coherently build new ideas related to the following disciplinary core ideas…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 [sic] 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 [sic] 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 [sic] 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 [sic] Fuels Unit, students' level[sic] 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 [sic] 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)" (Teacher Edition, page 105).

- Lesson 5: "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 the previous 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 towards each other' portion of the model developed in [sic] Electrostatics Unit (SEP: 2.4). Students apply this revised model to evaluate their predictive models and identify energy transfers, force interactions, and matter changes as bonds form (SEP: 2.4; CCC: 5.2; DCI: PS1.B.1, PS3.C.1). 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 which prompts students 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" (Teacher Edition, page 128). Here, development of an SEP element is discussed.

- Lesson 7: "This lesson is designed to coherently build ideas related to the following disciplinary core ideas…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 [sic] 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 [sic] Space Survival Unit to try to explain if 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). They 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 the 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; CCC: 3.1, 5.1; DCI: PS3.B.3)" (Teacher Edition, page 160).
- Lesson 10: "This lesson is designed to coherently build new ideas related to the following disciplinary core ideas…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, 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" (Teacher Edition, page 230).

- Lesson 14: "This lesson is designed to coherently build new ideas related to the following disciplinary core ideas…Students narrow down the number of fuels 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. They 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 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: ESS3A.2). They use these discussions to revise their arguments and reflect on the decision making[sic] process by considering what criteria/constraints they prioritized (SEP: 6.5, 7.3; DCI: ETS1A.1)" (Teacher Edition, page 293).

Suggestions for Improvement

- Consider the development of a user-friendly graphic to support teachers in understanding how specific elements are developed across courses and units (Teacher Edition, pages 21–24).
- Consider supplying information about prior learning in the SEPs and CCCs similar to the information about prior learning in the DCIs.
- Consider supplying more information about development of SEPs and CCCs, similar to the emphasis put on information about development of DCIs.

II.D. SCIENTIFIC ACCURACY

Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.	
Rating for Criterion II.D. Scientific Accuracy	Adequate

The reviewers found adequate evidence that most examples within the materials use scientifically accurate and grade-appropriate scientific information. All student-facing reading selections have a list of scientific references. However, there are a few cases in which inaccuracies are introduced in the unit.

There is guidance to help eliminate misconceptions and help support scientifically accurate learning. Related evidence includes:

- The unit provides adult-level learning about the science concepts in the unit. The resources on pages 28–29 give extra resources for teachers to guide students to a full scientific explanation. "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-oi l.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" (Teacher Edition, page 28).
- Lesson 1: "The fuel data card for LP gas ('propane') includes the chemical formulas for both propane…and butane.... 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" (Teacher Edition, page 42).
- Lesson 3: There is guidance to help the teacher ensure correct verbiage is used for "air" versus "gas." "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" (Teacher Edition, page 92).
- Lesson 4: "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" (Teacher Edition, page 105).
- Lesson 5: "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; 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" (Teacher Edition, page 128).

- Lesson 11: "The 'uranium' pellets pictured in Submarine Nuclear Reactors are actually uranium hexafluoride, UF. There are various technical reasons for the use of UF pellets, rather than pure uranium. The full explanation for this is outside the scope of this unit" (Teacher Edition, page 248).

Related evidence for inaccuracies includes:

- Lesson 5: "Plus, fossil fuels are likely to be used when crops to make biofuels are grown. This process is less efficient than just using fossil fuels, so biofuels can end up releasing even more carbon dioxide into the atmosphere than fossil fuels do" (C.5 Lesson 5 Handout Comparing Fuels, page 2). This statement could lead to possible misconceptions because biofuel production uses much less fossil fuel than production and use of fossil fuels directly.
- Lesson 5: "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, it may be helpful to ask them what we ultimately want to figure out in the unit, so they remember that we care about which fuels we should use" (Teacher Edition, page 140). In the NGSS, one of the Nature of Science ideas is that science does not tell us what we should do, so the emphasis here on "what we should do" is erroneously represented as science.
- Lesson 11: "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" (Teacher Edition, page 260). It is inaccurate to say that the dangers of nuclear reactors and nuclear waste are unanticipated. Scientists were aware of the possible dangers before developing nuclear energy. It is important for students to understand that there is a lot of nuance and debate about the role of ethics in science, and by classifying the downsides of nuclear power as "unanticipated effects" it absolves scientists of the responsibility of considering ethical implications.

Suggestions for Improvement

- Consider in Lesson 5 ensuring students become aware of the factual and logical inaccuracies of the Comparing Fuels argument as they consider the data and information from the article.

- Consider in Lesson 11 changing the claimed element.

II.E. DIFFERENTIATED INSTRUCTION

Provides guidance for teachers to support differentiated instruction by including:

i. Supportive ways to access instruction, including appropriate linguistic, visual, and kinesthetic engagement opportunities that are essential for effective science and engineering learning and particularly beneficial for multilingual learners and students with disabilities.

ii. Extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the targeted expectations.

iii. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.

Rating for Criterion II.E. Differentiated Instruction	Adequate

The reviewers found adequate evidence that the materials provide guidance for teachers to support differentiated instruction. Many general supports are called out in the unit. There are particularly strong and detailed supports for emerging multilingual learners. However, there are few specific strategies for supporting other groups of students. There are also few examples of alternative materials or strategies for how to individualize learning to support sense-making.

Frequent supports are provided for emerging multilingual learners. For example:

- "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" (Teacher Edition, page 28).
- Students co-construct the meaning of science words. "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" (Teacher Edition, page 30).

- In the home communication, parents are advised about this strategy for learning new words. "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" (Teacher Edition, page 33).
- Lesson 2: "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" (Teacher Edition, page 84).
- Lesson 3: "Supporting Multilingual Learners: The arrows and signs 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" (Teacher Edition, pages 91–92).
- Lesson 7: "Supporting emergent multilinguals: Students who are learning English may benefit from some alone time to process the prompts on slide H before sharing with a partner verbally. Consider giving students time to Stop and Jot their responses before sharing verbally with their partners" (Teacher Edition, page 165).
- Lesson 10: "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" (Teacher Edition, page 231).
- Lesson 11: "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" (Teacher Edition, page 247).
- Lesson 14: "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" (Teacher Edition, page 294).

There are Universal Design for Learning callouts in the margins of multiple lessons. These mostly deal with representation, student choice, and movement. There are some supports for students who "struggle." There are few specific supports described for students with disabilities or struggling readers. There is not specific guidance for students who are far above or below grade level for some learning. Related evidence includes:

- "What is the Learning in Places Nature-Culture Relations framework?…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" (Teacher Edition, page 30).

- Lesson 1: "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" (Teacher Edition, page 52).
- Lesson 12: "Literacy and Comprehension Support. For students who benefit from additional reading comprehension support, the Coherent Reading Protocol is well-suited for this text. The Coherent Reading 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" (Teacher Edition, page 272).

There are callouts to help students that may struggle. Assessment boxes have "what to look/listen for" and "what to do" responses to help students who need extra supports. These supports are tied into the learning task or assessment. There are not customized, specific strategies for some key learning. Related evidence includes:

- Lesson 2: Students revise their models of gasoline engines. There is general guidance to support struggling students. "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" (Teacher Edition, page 81). This is a key moment in learning that does not have specific alternative ways to support struggling students.
- Lesson 9: "If students struggle to identify the cascade of steps which 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" (Teacher Edition, page 223).

There are extension opportunities. However, it is sometimes unclear in some instances how the activity would deepen their three-dimensional learning or whether the alternate activity is for students who have met or exceeded the standard. Related evidence includes:

- Lesson 3: "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) 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)" (Teacher Edition, page 95). It is not clear if this is to be used for students who have already mastered the learning targets.
- Lesson 3: "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, they 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" (Teacher Edition, page 98). It is not clear if this is to be used for students who have already mastered the learning targets.

- Lesson 10: "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" (Teacher Edition, page 233). It is not clear if this is to be used for students who have already mastered the learning targets.
- Lesson 4: There is an 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" (Teacher Edition, page 116). It is not clear what element the extension opportunity builds on.
- Lesson 9: There is an extension opportunity with explicit questioning to help students look for patterns in data regarding ion concentrations. "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 show that they have the same molarity, which seems like it would result in the same concentration of ions in the solution. But that would not explain why the current would be higher through some of these than others. Say, Let's see what patterns we notice if we look at the calculations to determine how many of each type of ion that is produced from each salt at these molarities. Display slide BB. Distribute Ion Concentrations. Explain that the last two columns provide the results of those calculations while the column before shows us how those calculations can be 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 slide BB with a partner. Then discuss this as a class and follow-up with the second question below. ALTERNATE ACTIVITY Slide BB is optional and easily modified based on your students' needs. It is projected to take an additional 10 minutes. The reference provided here has all the related calculations completed, so that students can focus on the patterns in the last two columns vs. the first three columns. You could modify this handout to have students do some of these calculations. For example, you could remove what is shown in [sic] 2nd and 3rd rows and have students calculate the rest of those rows in partners (one person each row), using row 1 and 4 as worked examples. A video example of how to calculate such values can be found at: https://www.youtube.com/watch? v=7fHA17DOrB…How can these calculations help us explain the differences in the maximum current for each electrolyte solution? If we ensured that the number of ions in solution was the same with each

salt we test, do you think the type of atoms in each ion would also affect the current through the system?" (Teacher Edition, page 221).

- Lesson 11: "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 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)" (Teacher Edition, page 251). It is not clear if this is to be used for students who have already mastered the learning targets. A SEP is listed, but there is not guidance for the teacher on how to incorporate this SEP and how to deepen student understanding and use of that practice.
- Lesson 11: "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)" (Teacher Edition, page 255). It is not clear if this is to be used for students who have already mastered the learning targets.

Suggestions for Improvement

- Consider including more targeted support for students with disabilities, struggling readers, and students who are otherwise not meeting learning goals. This may include highlighting strategies that are already in place in the unit and specifying which kinds of needs the strategies might meet.
- Consider adding regular individualized support for different students. This could look like a lesson in which students who are struggling to meet learning goals engage with an alternative phenomenon while students who have already met the learning goals deepen their performance of a SEP beyond the scope of NGSS.
- Consider introducing or reintroducing ideas for helping students with reading early on in the unit, including the Coherent Reading Protocol, the CATCH method for annotations, and the Think Aloud strategies described in the Teacher Handbook.
- If extension activities are to be used with students who have already met the standards, consider describing how those activities could be integrated in the lesson and which part of the learning goals they would deepen.
- Consider adding to the Teacher Edition the page number(s) for strategies in the Teacher Handbook that are referenced in the lessons. This would help teachers more easily find the strategies as well as adapt lessons to meet the needs of a variety of students.

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

Supports teachers in facilitating coherent student learning experiences over time by:

i. Providing strategies for linking student engagement across lessons (e.g. cultivating new student questions at the end of a lesson in a way that leads to future lessons, helping students connect related problems and phenomena across lessons, etc.).

ii. Providing strategies for ensuring student sense-making and/or problem-solving is linked to learning in all three dimensions.

Rating for Criterion II.F. Teacher Support for Unit Coherence	Adequate

The reviewers found adequate evidence that the materials support teachers in facilitating coherent student learning experiences over time. In addition to the evidence provided in I.D., there is some evidence that teachers are provided extra support for connecting learning across lessons. Teachers are provided with guidance and routines that establish and reinforce coherence from a student's perspective, although it is not clear if students will understand how their learning in all three dimensions progresses. In addition, there is one instance where the flow of learning within a lesson lacks coherence from the teacher perspective.

There are some strategies to ensure student sense-making or problem solving is linked to learning in all three dimensions, but most of the emphasis is on DCIs. For example:

- Lesson 1: Students revise their models to incorporate new understandings. "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" (Teacher Edition, page 81).
- Lesson 3: "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 release a lot of carbon dioxide in combustion. Add questions to the DQB" (Teacher Edition, page 99).
- Lesson 7: "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 car cylinder system? Let's try to make sense of this" (Teacher Edition, page 161). "● How is the combustion reaction system above similar to the 'marbles' in the sim? ○ How is it different? ● As the

gasoline combusts, how do we know energy transfers out of the reaction? ● What might this outward transfer mean for the bond strength of reactants vs products?" (Lesson 7 Slides, Slide C).

- Lesson 8: "Move from a focus on magnets to a fuel. 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 magnets to carbon-based fuel combustion. Listen for these ideas: bonds break and form in both; and, the reaction is way bigger and more complicated" (Teacher Edition, page 179).
- Lesson 9: "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. Put up 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" (Teacher Edition, page 206).
- There are assessment opportunity boxes that cite how three-dimensional learning should occur and what to look/listen for. These can be helpful for providing feedback and support for students, but do not usually support students to see their own learning linked to the three dimensions.

There is guidance to help the teacher facilitate coherence across the unit. For example:

- The Teacher's Edition includes a Unit Storyline document, which provides a brief overview of each lesson in the unit. This Unit Storyline also includes a statement explaining how to navigate to the next lesson with key learning listed.
- Each lesson includes a section at the beginning of the lesson that summarizes what the student will do in the current lesson and the next lesson (e.g., page 35). Additionally, each lesson provides an overview of each component of the lesson in a Learning Plan Snapshot (e.g., pages 36–37).
- Each lesson includes a document that summarizes "Where We Are Going and NOT Going." This document provides clarification on which DCI, SEP, and CCC elements are being approached and often includes specific language explaining middle school units that may support current targets. This document also provides clarification about what the lesson materials are not attempting to develop (e.g., page 39).
- A graphic is provided to illustrate the structure of the unit. The graphic on page 15 includes lesson set questions and unit flow.
- Students frequently use Exit Tickets at the end of specific classes that are then used to open the following class with a discussion. This takes place within Lessons 1, 4, 5, 10, and 11.
- The Teacher Handbook describes the Navigation routine used to connect learning from one lesson to the next (Teacher Handbook, pages 19–20). Some examples of this and other navigation techniques include:
    - Lesson 1: There is a note for the teacher to look at the Exit Tickets to help with connections between lessons. "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" (Teacher Edition, page 52).

- Lesson 2: "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" (Teacher Edition, page 85).
- Lesson 3: There is an "Additional Guidance" section that informs the teacher what questions from the DQB this lesson relates to. "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?" (Teacher Edition, page 91).
- Lesson 4: "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" (Teacher Edition, page 121).
- Lesson 5: "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 the initial class consensus model, and to be prepared to share the ideas they see and hear during conversations with their partners during the upcoming class discussion" (Techer Edition, page 139).
- Lesson 9: "Navigate to the next lesson. Present slide FF. Ask, 'What other non-carbon based fuel source were we wondering about?' Look for students to say hydrogen. If students say uranium, ask which seems more similar to technologies we have already seen. Use fuel cards if needed and guide students toward the idea that hydrogen is more similar given it is used in some personal vehicles, and therefore might make more sense to investigate next" (Teacher Edition, page 225).
  Lesson 13: "Navigate. Present slide P. Ask, What should our next steps be with the Consensus Decision Matrix? Look for students to suggest: We should re-evaluate environmental impact 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" (Teacher Edition, page 287).

- Lesson 1: Teachers are instructed to develop a DQB. They are given guidance for how to organize the DQB and how to collect student ideas. This DQB is revisited by students in the unit.
- Lesson 7: Students develop a Progress Tracker. "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" (Teacher Edition, page 235).

There is verbiage within the lessons to help link student engagement across lessons. For example:

- Lesson 5: The lesson includes two goals, 1) that students understand that forming bonds releases energy, and 2) that students understand the benefits and tradeoffs of using biofuels vs.

fossil fuels. The reason for having these two goals in the same lesson is unclear from a teacher perspective. "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 impact fuels and their use have had on human populations (SEP: 7.2; DCI: ESS3.A.1, ESS3.B.1; CCC: 5.3)" (Teacher Edition, page 123).

Suggestions for Improvement

- Consider supporting students to see how their learning related to SEPs and CCCs supports their sense-making. For example, consider modifying tasks in the navigation routine to explicitly discuss targeted SEP and CCC elements such that students could see how these dimensions are useful to their sense-making.
- To enhance teachers' understanding of the unit, consider separating Lesson 5 into two lessons, one focused on bond formation releasing energy, and one focused on biofuels vs. fossil fuels.
- Consider color coding some of the major sense-making questions using blue, orange, and green so that students can visualize how their learning is linked to the three dimensions.
- Consider having students use and cite their Progress Tracker as they complete Lessons 14 and 15.

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.

Rating for Criterion II.G. Scaffolded Differentiation Over Time	Adequate

The reviewers found adequate evidence that the materials support teachers in helping students engage in the practices as needed and gradually adjusts supports over time in some cases, while in other cases, the level of support remains the same or increases with subsequent performances.

The unit supports students to become increasingly responsible for the **Argument from Evidence** SEP for some elements. This occurs within lessons such as in Lessons 7 and 12. There is also a transfer of responsibility of the practice as students work in whole groups and small groups, then create their argument in Lesson 14. However, there is a lot of specific guidance to support students in critiquing arguments in Lesson 14, which increases supports for critiquing arguments towards the end of the unit instead of reducing them. There is not the same level of support in earlier lessons where scaffolding and supports would be needed more.

- *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.* This unit reduces scaffolding for this element with the complexity of what students are comparing and evaluating. In Lesson 9, students evaluate a single design solution, in Lesson 12, they compare two design solutions, and in Lesson 13, they compare multiple design solutions.
    - Lesson 9: Students complete the battery design proposal independently, which is a single design solution. Students then go over learning in a Scientist Circle and complete a Progress Tracker entry. "The purpose of our discussion was not to decide if EVs are 'good or bad', but rather 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, and Improve framework in our Progress Tracker" (Teacher Edition, page 223).
    - Lesson 12: Students independently complete the Rocket Fuel Argument, which involves comparing two design solutions. "Write an evaluation for both nuclear and hydrogen rocket fuels answering the following question: Is there a rocket fuel that seems to address the engineering criteria and constraints best? Be sure to: Start your evaluation by identifying and justifying the most important criteria and constraints and explaining how you ranked the criteria of success. Then make an evaluation for which fuel choice should be made for our future space mission. Justify your evaluation using any measurements, or qualitative information from this lesson, past lessons. You may also include potential measurements that could be collected to be used for further evaluation" (C.5 Lesson 12 Assessment Rocket Fuel Argument).
    - Lesson 13: Students work in small groups to compare multiple design solutions. "● Work with your group to explore a transportation solution meant to curb our carbon emissions. ● Consider: ○ Engineering goal addressed ○ Supportive evidence for plan ○ Possible trade-offs made ○ Barriers in resource availability" (C.5 Lesson 13 Slides, Slide D).
- *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.* This unit reduces scaffolding for this element over time. In Lesson 7, students move from whole class critiques to small group critiques and then critique a hypothetical argument with a partner. In Lesson 14, they individually provide critiques.
    - Lesson 7: Students work with partners as they critique an argument. "Ask, using what we have seen and learned over the last few lessons, what critiques would you offer to a student who provided an answer to the following question? As you and your partner generate these critiques, be sure to consider how it can be phrased in order for your feedback to be respectful and constructive to this student" (Teacher Edition, page 166). There is an increase in student responsibility of the SEP in this lesson from the class discussion to critiquing an argument with a partner. Later in the lesson, students

respond to a hypothetical argument. "This example with hypothetical responses is a scaffold toward Lesson 14 in which students will provide extensive feedback on their classmates' design arguments" (Teacher Edition, page 167). Note that this progression is not referenced in Lesson 14, which is a missed opportunity to help students explicitly build on their understanding.

- Lesson 14: Students complete individual arguments. "Have students prepare individual drafts to argue for what they see as the best option(s) for their transportation solution. Present slide V. Say, Now that we have had a chance to discuss our ratings using the radar charts and a cost benefit analysis, I want you to individually identify which fuels we should consider to be the best options for future vehicles. Distribute [sic] Transportation Arguments Draft and give students the remaining class time to complete part 1" (Teacher Edition, page 301). Students share arguments with three peers, and they revise their arguments. There are specific scaffolding suggestions. "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)...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)" (Teacher Edition, page 302). "Ensure that students are given adequate time to complete these questions. It is important to give students the space and time as a way to develop the skills to successfully engage in argumentation with others in and outside of the classroom" (Teacher Edition, page 304). This level of specific guidance for the teacher is important, but less impactful than it could be as it is the last time the students use this SEP in the unit.

- *Construct, use, and/or present an oral and written argument or counterarguments based on data and evidence.* There is a reduction of scaffolding for this element across the unit as students go from whole groups to partners in Lesson 6. In Lesson 13, groups utilize some of the same skills of sharing and annotating (by outlining ideas) with less direct support, like the A/B sharing strategy in the previous lesson.
  - Lesson 6: Students discuss and model energy transfers as a class. There is questioning that helps make arguments from evidence. "How can we use these graphs to support an argument that energy is conserved throughout this entire process?...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" (Teacher Edition, pages 154–155). Note that students critique arguments and not an explanation,

so this note might be confusing to the teacher. There is an AB Partner strategy that scaffolds the practice of arguing from evidence from their models.
    - Lesson 13: Students evaluate a transportation solution using a decision matrix. They argue for sub-categories. They then consider revision of the Consensus Decision Matrix. "After five minutes, pair groups together to form larger groups. Each small group should share the subcategories and reasons for including them. Then as a larger group they will come to consensus on what to include on a list of subcategories that they will present to the class" (Teacher Edition, page 285). "Give groups time to outline their ideas and add additional evidence from [sic] Transportation System Solution Drawbacks, and [sic] Transportation System Solutions if needed, so that they feel prepared to share their ideas and field follow-up questions from their classmates" (Teacher Edition, page 286).

Students use the **Analyzing and Interpreting Data** SEP in many lessons. Students have opportunities to develop this practice. Related evidence includes:

- *Analyze data using tools, technologies, and/or models (e.g., computations, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.* In Lesson 8 students have single input at a time that goes into a calculation procedure to provide information. In Lesson 14, students have multiple complex inputs that are entered into a spreadsheet to produce a multi-dimensional output.
    - Lesson 8: "Choose a fuel for which to calculate carbon dioxide emissions. As you work through these calculations, consider how this data and the math can help you think about transportation solutions" (C.5 Lesson 8 Handout Calculating Carbon Emissions).
    - Lesson 14: "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 options against all five categories of criteria and constraints… Give groups the remainder of the class period to rate their options on the remaining four criteria (energy released, safety, environment, and infrastructure) using the information provided on [sic] Transportation Options" (Teacher Edition, pages 296–297).
- *Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.* In Lessons 4 and 10, students engage with this element as part of a whole class conversation, while in Lesson 11 they engage with it with a partner.
    - Lesson 4: "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" (Teacher Edition, page 110).
    - Lesson 10: "Revisit our criteria and constraints. Direct students' attention to the Criteria and Constraints poster 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 gases. If needed, point to the statement about CO emissions and ask, Is it just CO 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 [sic] Progress Tracker" (Teacher Edition, page 238).
    - Lesson 11: "What do the patterns in questions 3-4 tell us about how the numbers of protons and neutrons in the nucleus influence the forces keeping the nucleus together?" (C.5 Lesson 11 Handout Protons and Neutrons).
- *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.* In Lesson 9, students evaluate a single design solution, in Lesson 12, they compare two design solutions, and in Lesson 13, they compare multiple design solutions.
    - Lesson 9: "The purpose of our discussion was not to decide if EVs are 'good or bad', but rather 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, and Improve framework in our Progress Tracker" (Teacher Edition, page 223).
    - Lesson 12: "Write an evaluation for both nuclear and hydrogen rocket fuels answering the following question: Is there a rocket fuel that seems to address the engineering criteria and constraints best? Be sure to: Start your evaluation by identifying and justifying the most important criteria and constraints and explaining how you ranked the criteria of success. Then make an evaluation for which fuel choice should be made for our future space mission. Justify your evaluation using any measurements, or qualitative information from this lesson, past lessons. You may also include potential measurements that could be collected to be used for further evaluation" (C.5 Lesson 12 Assessment Rocket Fuel Argument).
    - Lesson 13: "● Work with your group to explore a transportation solution meant to curb our carbon emissions. ● Consider: ○ Engineering goal addressed ○ Supportive evidence for plan ○ Possible trade-offs made ○ Barriers in resource availability" (C.5 Lesson 13 Slides, Slide D).

Examples of elements where scaffolding increases or remains the same include:
- *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.* In both Lessons 2 and 10, students engage with this element through a teacher-facilitated whole-class discussion.
    - Lesson 2: "With your class ● What were some of the differences between the types of fuels? ● What needs to happen to the fuel for the vehicle to be forced forward? ● What characteristics might make a fuel ideal to use in a vehicle?" (C.5 Lesson 2 Slides, Slide DD).
    - Lesson 10: "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. For each prompt, invite students to raise one finger if the refueling option is close to school or where you live and two fingers if it is far: How far do you need to travel to refuel a vehicle with a carbon-based fuel, like gasoline, diesel, or biodiesel? How far do you need to travel to recharge a battery or refuel a hydrogen vehicle? Accept all answers and share what you notice as you scan the class. 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 computers to divide and conquer exploration of the two websites… 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" (Teacher Edition, pages 238–239).

- *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.* In Lesson 11, teachers are encouraged to prompt students to assume that theories and laws work across time, while no such prompt was provided in Lesson 2.
    - Lesson 2: "In your notebook ● Observe the Syringe Piston Demonstration. ● After you observe the demonstration, answer these questions: ○ What happens to the syringe volume? ○ What evidence of forces do you see? ○ What is causing the forces? ○ How is energy transferred by the forces?" (C.5 Lesson 2 Slides, Slide Z).
    - Lesson 11: "SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS 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" (Teacher Edition, page 249).
- *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.*
    - Lesson 9: Students independently complete the design proposal. "Make a battery design proposal. Display slide DD. Suggest that our combination of electrolytes we analyzed today and metals we measured yesterday give us the kind of data that engineers use to try to figure out how to design more effective batteries. Tell students to draw on that data and their investigation data to support a battery design proposal they would make in answer to 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 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 submit their design proposal through the electronic form" (Teacher Edition, page 223). There is guidance on how to provide scaffolding as students complete this.

- Lesson 14: There is not a clear reduction in scaffolding as Lesson 9 requires more independence with the battery design proposal than Lesson 14 with the group, peer sharing, and then individual revision of their solution as they consider the best design proposal. There is an increase in scaffolding as the materials share many prompts to help students that the teacher should pose. "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?" (Teacher Edition, page 302).

Suggestions for Improvement

- Consider including more explicit verbiage for the teacher about reducing scaffolds throughout the unit, such as describing who is doing the task and what help is provided within a specific SEP element across the scope of the unit.
- Consider increasing the number of targeted SEP elements that are developed in the unit through scaffold reduction, such as increasing student independence by moving from whole groups to small groups to individual activities for elements that are brand new to students
- Consider including guidance to have students refer back to scaffolded experiences. For example, the hypothetical argument in Lesson 7 could help them in Lesson 14.

OVERALL CATEGORY II SCORE:
3
(0, 1, 2, 3)

Unit Scoring Guide – Category II	
Criteria A-G	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

CATEGORY III

MONITORING NGSS STUDENT PROGRESS

III.A. MONITORING 3D STUDENT PERFORMANCES

III.B. FORMATIVE

III.C. SCORING GUIDANCE

III.D. UNBIASED TASK/ITEMS

III.E. COHERENT ASSESSMENT SYSTEM

III.F. OPPORTUNITY TO LEARN

III.A. MONITORING 3D STUDENT PERFORMANCES

Elicits direct, observable evidence of three-dimensional learning; students are using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.

Rating for Criterion III.A. Monitoring 3D Student Performances	Extensive

The reviewers found extensive evidence that the materials elicit direct, observable evidence of students using practices with DCIs and CCCs to make sense of phenomena or design solutions to problems. There are three-dimensional assessment opportunities in almost every lesson of this unit, and in many lessons there is more than one assessment. Formal assessments are related to phenomena or problems. However, in some cases, one or two elements claimed are not fully assessed.

Related evidence includes:

- Lesson 1: "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. 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)" (Teacher Edition, page 45).
- Lesson 1: Assessment 1.B.2 is completed in partners, and thus would not provide individual-level artifacts of student performances.
- Lesson 2: Assessment 2.A.1 is completed in small groups and shared as a whole class, and the teacher is not prompted to collect individual-level artifacts of student performance (Teacher Edition, pages 63–64).
- Lesson 2: "Stop and Jot ● What is happening between the fuel tank and the wheels? ● How do these parts work together to make a vehicle move?" (C.5 Lesson 2 Slides, Slide I). "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)" (Teacher Edition, page 66). However, students do not use a variety of sources for their evidence and do not assume that theories and laws are consistent throughout time (SEP **6.2**).
- Lesson 2: "Revise models to incorporate new understandings. Display slide CC. Distribute [sic] 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…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)" (Teacher Edition, pages 80–81).

- Lesson 3: Assessment 3.A.2 is a whole-class conversation and the teacher is not prompted to collect individual-level artifacts of student performance (Teacher Edition, pages 82–83).
- Lesson 4: Assessment 4.A.1 is a small group discussion followed by a whole-class conversation and the teacher is not prompted to collect individual-level artifacts of student performance (Teacher Edition, page 110).
- Lesson 4: "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…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)" (Teacher Edition, page 120).
- Lesson 5: Assessment 5.A.2 is an individual activity [MOU1], partner conversation, and whole-class discussion. It seems that the partner and whole-class discussion are emphasized, so the assessment would be unlikely to yield enough individual-level artifacts of student performance (Teacher Edition, pages 132–133).
- Lesson 5: "Reflect: Was your prediction about the relationship between distance and energy output correct? What did you observe in the simulation that supports or refutes your prediction? You used two different models to investigate bond formation: the ruler and marble system and the simulation. What are the merits and limitations of each of these for modeling, investigating, and explaining energy transfer during bond formation?" (C.5 Lesson 5 Handout Predicting Energy Changes, page 3). "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)" (Teacher Edition, page 138).
- Lesson 6: Assessment 6.A.1 is an individual handout and whole-class activity and discussion, with emphasis on the whole-class portion and is thus unlikely to yield helpful individual-level artifacts of student performance (Teacher Edition, page 153).
- Lesson 6: "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? 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" (C.5 Lesson 6 Handout Modeling Energy Changes). "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)" (Teacher Edition, page 156).

- Lesson 7: Assessment 7.B.1 is a whole-class discussion and the teacher is not prompted to collect individual-level artifacts of student performance (Teacher Edition, pages 169–170).
- Lesson 7: "We started the lesson by evaluating the claim 'Diesel has a greater energy released because it starts with stronger bonds.' Revise that claim using the evidence above to reflect a more supported claim" (C.5 Lesson 7 Handout Fuel Energy Released, page 1). "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) (Teacher Edition, page 171). However, students do not need to use the claimed **5.1** CCC element in their responses.
- Lesson 8: Assessment 8.A.1 is a whole-class discussion and the teacher is not prompted to collect individual-level artifacts of student performance (Teacher Edition, pages 180–181).
- Lesson 8: "Use the graphs you identified from Question 4a and 4b as a model to explain how energy transfers caused the temperature change you observed. Focus on reactants (calcium chloride) and final products (calcium and chloride ions). You may use words and/or drawings in your response" (C.5 Lesson 8 Assessment Hot Pack Assessment, page 4). "Building toward: 8.A.3 Develop a model based on evidence to illustrate energy transfer out of a chemical reaction system depending on energy transfer in and out of fields as particular bonds break and form. (SEP: 2.3; CCC: 5.2; DCI: PS1.A.4, PS1.B.1)" (Teacher Edition, page 194). In this assessment, students transfer what they have learned about bond formation and bond breaking to understand how hot packs or cold packs work.
- Lesson 9: Assessment 9.A.1 is a whole-class discussion and the teacher is not prompted to collect individual-level artifacts of student performance (Teacher Edition, pages 205–206).
- Lesson 9: "Make a battery design proposal. Display slide DD. Suggest that our combination of electrolytes we analyzed today and metals we measured yesterday give us the kind of data that engineers use to try to figure out how to design more effective batteries. Tell students to draw on that data and their investigation data to support a battery design proposal they would make in answer to 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 why. Remind students to draw on the 'Batteries' poster and their M-E-F poster thinking for this part of their design argument…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; CCC: 2.2; DCI: PS3.A.4)" (Teacher Edition, page 223).
- Lesson 10: Assessment 10.A.2 is completed as a partner activity and the teacher is not prompted to collect individual-level artifacts of student performance (Teacher Edition, pages 238–240; C.5 Lesson 10 Slides, Slide T).

- Lesson 11: Assessment 11.A.1 is a whole-class discussion and the teacher is not prompted to collect artifacts of individual-level student performance (Teacher Edition, page 253; C.5 Lesson 11 Slides, Slide L).
- Lesson 11: "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" (C.5 Lesson 2 Handout Progress Tracker, page 1). "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)" (Teacher Edition, page 262). However, students do not need to take into account unanticipated effects (**SEP 6.3**).
- Lesson 12: "Students argue their fuel choice using evidence. Display slide H, pass out [sic] Rocket Fuel Argument, and tell the students that they will now be arguing which fuel choice, if any, meets the needed criteria and constraints for an optimal rocket fuel. Students' argument should begin by defining the problem this fuel choice is looking to overcome, followed by which, if any, fuel they would recommend for our Mars missions, and their rationale for this choice…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)" (Teacher Edition, page 273). In this task, students consider fuels for rockets used for space exploration. Note that students do not need to use the high school-level DCIs claimed in this prompt, as a middle school-level of understanding would suffice.
- Lesson 13: "Using the class consensus decision matrix, analyze the viability of the proposed transportation solutions seen earlier" (C.5 Lesson 13 Slides, Slide 283). "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)" (Teacher Edition, page 284). Note: students investigate a single cause and don't show evidence of using the claimed CCC element.
- Lesson 14: Assessment 14.A.2 is a small group conversation and whole-class discussion and the teacher is not prompted to collect artifacts of individual-level student performance (Teacher Edition, pages 298–299).
- Lesson 14: "Give students 3 minutes to complete the cost-benefit analysis for their first transportation option on Cost-Benefit Analysis. Remind them that their individual values ratings also need to be factored into each criterion and constraint. Encourage students to have yourself or a peer check their work before moving onto a cost-benefit analysis for another transportation option. Present slide T when all students have successfully completed one cost-benefit analysis calculation so they know to move onto the calculation tables for the rest of their options…Building toward 14.A.3 Analyze data using quantitative tools in order 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)" (Teacher Edition, page 300).

- Lesson 15: "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) transfer 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 emissions. •Discuss the other criteria you prioritized when making your decision. How did they impact it? What tradeoffs did you consider? •Explain the impact you believe your proposal will have on your community and society at large. Use evidence from your design matrix as needed" (C.5 Lesson 15 Handout Final Design Proposal). "Building toward 15.A.1 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)" (Teacher Edition, page 311). In this task, students argue for their selected next-generation transportation solution.

Formal tasks require students to apply their learning to an aspect of the unit phenomenon. In some instances, the elements assessed are not cited as targeted elements, and there are some targeted SEP elements that are not assessed formally. Related evidence includes:

- Lesson 5: "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)" (Teacher Edition, page 133). The Exit Ticket for this lesson uses an element of the SEP of **Developing and Using Models**, which is not designated as a targeted SEP element.
- Lesson 9: "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; CCC: 2.2; DCI: PS3.A.4)" (Teacher Edition, page 223). The summative assessment for this lesson identifies the SEP of **Developing and Using Models**, which is not a targeted SEP.
- Lesson 14: "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 their arguments. (SEP: 6.5, 7.3; DCI: ETS1.A.1, ESS3.A.2; CCC: 1.4)" (Teacher Edition, page 302). This is a draft of a student-produced argument that is completed in Lesson 15, but the targeted element of the SEP of **Arguing from Evidence** is not evaluated according to the scoring guidance.
- None of the elements of the targeted SEP of **Analyzing and Interpreting Data** are assessed in the formal tasks of the unit, such as an Electronic Exit Ticket.

Suggestions for Improvement

- Consider adjusting one-dimensional assessments to include at least two dimensions at the high school level.
- Consider adding instructions for how teachers can capture individual student data from group assessments.
- Consider adjusting the assessments so that they clearly target the aspect of each targeted element that differentiates it from the corresponding middle school-level element.
- Consider providing at least one assessment opportunity for each of the targeted SEP elements.

III.B. FORMATIVE	
Embeds formative assessment processes throughout that evaluate student learning to inform instruction.	
Rating for Criterion III.B. Formative	Adequate

The reviewers found adequate evidence that the materials embed formative assessment processes throughout that evaluate student learning and inform instruction. There are multiple formative assessments embedded throughout the unit and after key learning within the unit. Some guidance is provided to help inform instruction; sometimes the "what to do" explains how to respond to students or adjust instruction, but sometimes the "what to do" only provides instructions for facilitating the assessment as opposed to feedback and responding to instruction. Formative assessments usually provide only one way for students to demonstrate their thinking.

Related evidence includes:

- The Assessment System Overview provides guidance for when different assessments occur in the lesson (Teacher Edition, pages 318–325). The materials explicitly claim formative assessments in Lessons 3, 4, 5, 6, 7, 8, 9, 12, 13, 14, and 15. For example:
    - "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" (Teacher Edition, page 319).
    - "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" (Teacher Edition, page 321).
    - "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" (Teacher Edition, page 322).
- The Lesson-by-Lesson Assessment Opportunities provides a document to see where to "check for understanding." (Teacher Edition, pages 326–335). Some are not explicitly labeled as formative but can be used as formative assessment opportunities.
- Multiple assessment opportunities exist in the lessons that can be used as formative. There is some guidance for helping provide feedback and inform instruction based on different student responses. However, some guidance lacks the detail to attend to different levels of student performance or the guidance is based solely on how to administer the formative. Some strong examples of helping provide feedback to inform instruction include:
    - Lesson 4: "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" (Teacher Edition, page 121).
    - Lesson 5: "If students struggle to discuss matter changes, either run the simulation or repeat the Marble Investigation 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 Alternate Activity guidance below. 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 [sic] 'Total Kinetic Energy of all Particles' graphs on the simulation. Also encourage students to look at the values of 'Energy Stored in the

Field' as the starting distance of the metal marble/ marble B is changed" (Teacher Edition, page 135).

- Lesson 7: "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" (Teacher Edition, page 162).
- Lesson 8: "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 [sic] Carbon Calculations Key. Questions 4, 5, and 8 on Calculating Carbon Emissions are the calculations students will do to determine the amounts of CO and SO 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" (Teacher Edition, page 187).
- Lesson 9: "What to do: Use the discussion tracker 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 tracker. 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" (Teacher Edition, page 206).

Some examples of weak guidance include:

- Lesson 2: "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…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" (Teacher Edition, pages 80–81).

- Lesson 13: "What to do: Walk around the room and put TWO stamps on [sic] STAMP Protocol Matrix if they have accomplished both of these bullets. Put ONE stamp on [sic] STAMP Protocol Matrix if they have accomplished ONE of these bullets or PART of each bullet. If students do not get TWO stamps, push them to focus on positives and negatives of both transportation solutions, as well as causality and attempt to revisit these students. 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; 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" (Teacher Edition, page 284).
- Lesson 14: "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 the Transportation Options. If students are quantifying each solution 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 solutions based on the criteria and constraints, prompt them to consider if the solution is more or less optimal for that particular criterion or constraint. Then, remind them of the numerical relationship established in slide H to elicit a numerical value" (Teacher Edition, page 279). "What to do: Push students to focus on missing elements of the bullets listed above, or what they learned as a result of their conversation with their peers. Use some of the following guiding questions to evaluate the qualities of their arguments: How have students quantified the value of each transportation solution they 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" (Teacher Edition, page 300). The self-assessment may not provide purposeful feedback for students and there's no guidance on how the teacher could use that self-assessment to inform instruction.

Suggestions for Improvement

- Consider adding "what to do" instructions related to adjusting instruction for every formative assessment.
- Consider including alternative methods of assessment with each formative assessment.

III.C. SCORING GUIDANCE	
Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.	
Rating for Criterion III.C. Scoring Guidance	Extensive

The reviewers found extensive evidence that the included aligned rubrics and scoring guidelines help the teacher interpret student performance for all three dimensions. The unit includes aligned rubrics and scoring guidance that provides support for interpreting student performance, planning future instruction, and providing ongoing feedback. However, although teachers are provided guidance for interpreting student performance, students themselves are not.

Within assessment boxes, there is "what to look/listen for" guidance to help the teacher interpret student performance. These also reference specific elements that should be in student answers. However, some claimed elements are not present in the task. Some examples include:

- Lesson 2: "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[sic] objects to move. (DCI: PS1.B.1; CCC: 5.2)" (Teacher Edition, page 78).
- Lesson 4: "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)" (Teacher Edition, page 120).
- Lesson 5: "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" (C.5 Lesson 2 Handout Progress Tracker, page 1). "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 impact fuels and their use have had on human populations (SEP: 7.2; DCI: ESS3.A.1, ESS3.B.1; CCC: 5.3)" (Teacher Edition, page 142).

However, the use of fossil fuels is not a geologic event, so students are unlikely to use DCI **ESS3.B.1**. In addition, students do not need to use CCC **5.3** in this assessment.

- Lesson 8: "What do 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 flow within, in, 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)" (Teacher Edition, page 183).
- Lesson 10: "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 which 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 gases to criteria and constraints on a transportation system. (SEP: 4.6)" (Teacher Edition, page 240).

Detailed scoring guidance with levels of student responses are provided for some assessments. These have three levels of understanding and a student example of work. Examples include:

- Lesson 8: Cold Pack/Hot Pack (Teacher Edition, pages 377–399).
    - "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; CCC: 5.2; DCI: PS1.A.4, PS1.B.1) 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 in or out of a chemical reaction system depending on energy transfer in and out of fields as particular bonds break and form. (SEP: 2.3; CCC: 5.2; DCI: PS1.A.4, PS1.B.1) 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 7.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" (Lesson 8 Cold Pack Key/Rubric, page 1).
    - "Foundational Pieces: 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. Linked Understanding: 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. Organized Understanding: 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" (Lesson 8 Cold Pack Key/Rubric, page 7).

- Lesson 9: Battery Design (Teacher Edition, pages 407–409).
- Lesson 12: Rocket Argument (Teacher Edition, pages 421–424).
- Lesson 15: The Final Design (Teacher Edition, pages 437–440).

Sample student responses with purple/other color text are provided for some assessments. These tend to provide the ideal answer. Examples include:

- Progress Tracker (Teacher Edition, pages 341–345).
- Lesson 4: Energy and Forces (Teacher Edition, page 353).
- Lesson 4: Mapping Models (Teacher Edition, pages 355–356).
- Lesson 6: Modeling Energy (Teacher Edition, pages 369–371).
- Lesson 8: Carbon Calculations (Teacher Edition, pages 373–375).

Some assessments have a correct response and include a rationale for the correct response. This provides some additional guidance but does not provide guidance for a range of student responses. Examples include:

- Lesson 5: Exit Ticket (Teacher Edition, pages 363–367).
- Lesson 11: Exit Ticket (Teacher Edition. pages 417–420).

The STAMP Protocol is used in multiple lessons and includes "what to look for" guidance. An example includes Lesson 13. "Look-fors: 13.A .1 (slide J) Students consider the effects of implementing a new transportation solution as well as estimate the size of effect 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)" (Teacher Edition, page 428).

Suggestions for Improvement

- Consider providing more explicit verbiage after self-assessment opportunities so students are aware of and can monitor their own progress more effectively.
- Consider more often providing different levels of student responses rather than just the one sample answer.

III.D. UNBIASED TASK/ITEMS

Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.

Rating for Criterion III.D. Unbiased Task/Items	Extensive

The reviewers found extensive evidence that the materials assess student proficiency using accessible and unbiased methods, vocabulary, representations, and examples. The amount of text in unit assessments is appropriate and students have opportunities to show their thinking in a variety of ways throughout the unit. In assessments, there are a few opportunities for students to have choice in how they show their thinking. There are several opportunities for students to choose aspects of their tasks, such as contexts. When a new scenario is presented, there are appropriate scaffolds for it.

There are callouts to help with accessibility for the tasks and items within the unit. Related evidence includes:

- Lesson 2: "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" (Teacher Edition, page 72).
- Lesson 2: "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" (Teacher Edition, page 84).
- Lesson 5: "Allow students to use math, grid paper, and the cutout boxes to calculate these results. 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" (Teacher Edition, page 169).

All three summative assessments in the unit include considerable on-ramping, including a variety of entry points to prepare students for optimal performance. The vocabulary and content are at a level that is appropriate for high school students. For example:

- Lesson 8: "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 of processing the scenario being reduced. 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 [sic] Cold Pack Scenario or [sic] Hot Pack Scenario they may need help with processing. This will support students later as they complete the mid-unit assessment" (Teacher Edition, page 191).
- Lesson 12: The main activities in Lesson 12 serve as on-ramping to the final argumentation task. "ORIENTING TO SPACE TRAVEL PHENOMENA Help students clarify an engineering challenge for future space missions by investigating the negative impacts of space travel. CLASS ROCKET CRITERIA AND CONSTRAINT CONSENSUS TABLE Lead a Scientists Circle for students to develop a list of criteria and constraints from the criteria and constraints of future space missions. EVALUATING 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 those criteria and constraints. ARGUMENT FOR FUEL CHOICE Give students time to compare nuclear and hydrogen rocket fuel in a written argument" (Teacher Edition, page 266).
- Lessons 13 and 14 prepare students for the final assessment in Lesson 15:
    - Lesson 13: "We create a draft decision matrix and use it to evaluate transportation solutions on the basis of 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 we can evaluate solutions systematically. We work in small groups to develop subcategories for the other criteria and constraints in the Consensus Decision Matrix" (Teacher Edition, page 275).
    - Lesson 14: "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" (Teacher Edition, page 289).
    - Lesson 15: "We use our prioritized criteria, arguments from Lesson 14, and feedback on our arguments to propose a transportation solution. We use what we have 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" (Teacher Edition, page 307).

There are a few opportunities for student choice in how they present their knowledge. For example:

- Lesson 5: Students have a choice in how they represent their thinking on the hot/cold pack assessment. “Question 5: Use the graphs you identified from Question 4a and 4b as a model to explain how energy transfers caused the temperature change you observed. Focus on reactants (calcium chloride) and final products (calcium and chloride ions). You may use words and/or drawings in your response” (Teacher Edition, page 384). “Question 5: Use the graphs you identified from Question 4a and 4b as a model to explain how energy transfers caused the temperature change you observed. Focus on reactants (potassium chloride) and final products (potassium and chloride ions). You may use words and/or drawings in your response” (Teacher Edition, page 396).
- Lesson 15: Students have the option to use just words or use models alongside their explanation. “Explain how your chosen option(s) transfer 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 (Teacher Edition, page 437).

There are opportunities for students to choose how to interact with new information or the context of their tasks. For example:

- Lesson 1: “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 sources” (Teacher Edition, page 42).
- Lesson 2: “Universal Design for Learning: 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” (Teacher Edition, page 72).
- Lesson 4: “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” (Teacher Edition, page 113).
- Lesson 8: “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” (Teacher Edition, page 191).
- Lesson 9: “Direct students to choose only one of the four to evaluate, as they will hear from other students with different arguments during the following Scientists Circle. Encourage them

to pick an argument that surprises them or might differ from their current thinking. Give them 8 minutes to read and annotate their chosen handout" (Teacher Edition, page 203).

- Lesson 11: "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" (Teacher Edition, page 255).
- Lesson 11: "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" (Teacher Edition, page 260).

Suggestions for Improvement

Consider more opportunities for students to have choices in how they show their learning, particularly on smaller assessments throughout the unit and on the Progress Tracker.

III.E. COHERENT ASSESSMENT SYSTEM

Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.

Rating for Criterion III.E. Coherent Assessment System	Extensive

The reviewers found extensive evidence that the materials include pre-, formative, summative, and self-assessment measures that assess three-dimensional learning. The Assessment System Overview outlines the different kinds of assessment used in the unit. This document shows how formal formative and summative assessments match the three-dimensional learning goals of the unit. Most assessments connect to the targeted learning goals.

There is coherence and purpose for the assessments throughout the unit. Related evidence includes:

- There is a "Lesson-by-Lesson Assessment Opportunities" document within the Teacher Edition that explains the LLPEs, when to check for understanding, and what to look/listen for related to specific elements of the learning goals (Teacher Edition, pages 326–335).
- There is an "Assessment System Overview" that outlines the purpose of each assessment within each lesson (Teacher Edition, pages 318–325).
- Within each assessment opportunity box, there is guidance about how the check for understanding or assessment is tied to three-dimensional learning. However, not all of this

guidance accurately represents what students do in the assessment (see related evidence under Criteria I.B and III.A).

- Lesson 12: This assessment is cited as an optional lesson and assessment that can be used by the teacher in a variety of ways based on what makes sense in their assessment system. "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 [sic] 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" (Teacher Edition, page 332).

A formal Pre-Assessment opportunity is mentioned in the unit. In Lesson 1, the initial model, constructed by individual students, serves as a pre-assessment. This pre-assessment addresses only a few of the elements of the unit. Teachers are advised on how to provide feedback to students. "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" (Teacher Edition, page 44).

Formative Assessment opportunities are found throughout the unit. Related evidence includes:

- Informal formative assessments are found throughout the unit in the sections called Assessment Opportunities. These include three-dimensional learning targets. See related evidence under Criteria III.B and III.C.
- Formal formative assessments are found periodically in the unit and include three-dimensional learning goals as well as answer keys. Some include more detailed rubrics. The unit also introduces a method for using a STAMP protocol to give feedback on student work.

Summative Assessment

- In the Assessment System Overview, summative assessments are described for Lessons 8, 11, 12, and 15.
- Lesson 8: The Cold Pack and Hot Pack are completed at the end of the lesson. Learning goals are stated on the key. "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; CCC: 5.2; DCI: PS1.A.4, PS1.B.1) 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 in or out of a chemical reaction system depending on energy transfer in and out of fields as particular bonds break and form. (SEP: 2.3; CCC: 5.2; DCI: PS1.A.4, PS1.B.1) 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 7.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" (Lesson 8 Answer Key, Cold Pack Key/Rubric, page 1). Questions require the use of the elements of the three dimensions described in the learning goals.

- Lesson 11: Students complete an Exit Ticket. Three-dimensional learning goals are stated on the Answer Key. "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)" (Lesson 11 Answer Key, Electronic Exit Ticket Key, page 1). Questions require at least partial use of the elements of the three dimensions described in the learning goals.
- Lesson 15: An end of unit assessment is completed individually. Three-dimensional learning goals are stated on the 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 Lesson Level Performance Expectation are assessed, see the NGSS Element Alignment table below" (Lesson 15 Answer Key, Final Design Key, page 1). Coverage of elements of the three dimensions are shown in the rubric using colored type to indicate SEPs, DCIs, and CCCs.

Self-assessment opportunities are provided in the unit, but these opportunities do not cover most of the learning goals in the unit. For example:

- Lesson 4: Students have a self-assessment question on an Exit Ticket. "How confident are you in using data and thinking about energy flows? Explain" (Teacher Edition, page 120).
- Lesson 5: There is an alternate activity where students can self-assess their performance in giving or receiving feedback, but this does not connect to many of the learning goals in the unit.
- Lesson 7: Students revisit the DQB. "Lead a class discussion to have students self-assess what we have figured out and which questions we still need to address" (Teacher Edition, page 172). There is an alternate activity where students can self-assess their performance in giving or receiving feedback, but this does not connect to many of the learning goals in the unit.
- Lesson 8: Students pick DQB questions to answer and then prepare a written answer. They mark these answered questions on the DQB and then ask clarifying questions.
- Lesson 15: "Reflect on what we accomplished in this project. Present 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 [sic] Transportation Proposal

Reflection and give students five minutes to reflect on their learning independently" (Teacher Edition, page 314).

Suggestions for Improvement

- Consider giving more emphasis to the targeted elements in **Engaging in Argument from Evidence** on unit assessments.
- Consider providing more pre-assessment and self-assessment opportunities that align with the full breadth of the learning goals of the unit.

III.F. OPPORTUNITY TO LEARN

Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.

Rating for Criterion III.F. Opportunity to Learn	Extensive

The reviewers found extensive evidence that the materials provide opportunities for students to demonstrate performance of practices connected with their understanding of DCIs and CCCs. There are opportunities for students to revise their learning based on feedback throughout the unit. There are appropriate tasks for students to demonstrate their learning three-dimensionally. Modeling is done throughout the unit, and there are multiple iterations of their models. However, modeling is not a claimed SEP that is intentionally developed.

Students have multiple opportunities to develop and write arguments, get some feedback on their work, and then apply that feedback by developing an argument on a different topic. Related evidence includes:

- Lesson 9: Students write in their Progress Trackers to reflect on information that can be used in an argument about the use of electric vehicles. Ideas for teacher feedback are included. "Pay particular attention to the progress tracker entries of students who did not speak much during the earlier discussion associated with this LLPE. Encourage students to tie ideas about how batteries work they figured out in this lesson 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" (Teacher Edition, page 224).
- Lesson 12: "Write an evaluation for both nuclear and hydrogen rocket fuels answering the following question: Is there a rocket fuel that seems to address the engineering criteria and

constraints best? Be sure to: Start your evaluation by identifying and justifying the most important criteria and constraints and explaining how you ranked the criteria of success. Then make an evaluation for which fuel choice should be made for our future space mission. Justify your evaluation using any measurements, or qualitative information from this lesson, past lessons. You may also include potential measurements that could be collected to be used for further evaluation" (Lesson 12 Assessment Rocket Fuel Argument). Individual student work is evaluated by the teacher and feedback is provided. "Feedback: Review the connections between chemical and nuclear fueled rockets and their impacts in the global system. Ideas for Instruction: 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" (Lesson 12 Answer Key Rocket Argument).

- Lesson 13: Students prepare arguments about different transportation systems. They receive feedback from the teacher about their thinking. "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 [sic] STAMP Protocol Matrix if they have multiple subcategories for their criterion AND evidence for the specified subcategories. Put ONE stamp on [sic] STAMP Protocol Matrix if they have subcategories but lack evidence. If students do not get TWO stamps, push them to go back to the readings and fuel cards and connect subcategories to specific evidence" (Teacher Edition, page 286).
- Students have the chance to revise their arguments in Lessons 14 and 15.

Students have a chance to respond to feedback from peers and the teacher. Related evidence includes:

- Lesson 4: "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" (Teacher Edition, page 115). "...collect Mapping Between Models after the discussion and look for places where students revised their thinking" (Teacher Edition, page 319). There is a missed opportunity to have specific, targeted feedback and have students learn from the feedback.
- Lesson 4: "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" (Teacher Edition, page 121).
- Lesson 5: "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 the initial class consensus model, and to be prepared to share the ideas they see and hear during conversations with their partners during the upcoming class discussion. Tell students to spend about a minute each explaining their explanation to their partner, and then spend the

next two minutes giving each other feedback…With a partner Share your explanation for how fuel combustion releases energy if it takes energy to break bonds. Give each other feedback" (C.5 Lesson 5 Slides, Slide N). "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, in addition to 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 and routines and more tools for peer assessment may be found in the OpenSciEd Teacher Handbook: High School Science" (Teacher Edition, page 139).

- Lesson 6: "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" (Teacher Edition, page 155).
- Lesson 13: "You may listen to groups and provide feedback at a group level, or use student notes to provide individual feedback" (Teacher Edition, page 286).
- Lesson 14: Students share arguments with peers, and they then revise their arguments considering the peer feedback and teacher feedback through the STAMP protocol. "Reflect on peer discussions to revise arguments. Present slide Z. Give students about 7 minutes to complete parts 2 and 3 of [sic] Transportation Arguments Draft which ask students to revise their arguments. ✱ 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 [sic] Transportation Arguments Draft. As students work to complete parts 2 and 3 of [sic] Transportation Arguments Draft, conduct the STAMP Protocol check for this lesson using [sic] STAMP Protocol Matrix" (Teacher Edition, page 303).
- Lesson 14: "Encourage students to have yourself or a peer check their work before moving onto a cost-benefit analysis for another transportation option" (Teacher Edition, page 300). This is an opportunity for feedback on accuracy of executing a procedure rather than on three-dimensional thinking.
- Lesson 15: "If students need more time to finalize their design proposal, you could ask students to turn in what they have, provide feedback on this, and then allow them to complete the final design proposal outside of class… See [sic] 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 stamps may provide immediate feedback to students about their progress and your expectations for them to revise" (Teacher Edition, page 311).

Suggestions for Improvement

Consider ensuring that all focal SEP elements are assessed at the individual level more than once for students to be able to individually demonstrate their proficiency.

OVERALL CATEGORY III SCORE: 3 (0, 1, 2, 3)	
Unit Scoring Guide – Category III	
Criteria A-F	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

SCORING GUIDES FOR EACH CATEGORY

UNIT SCORING GUIDE – CATEGORY I (CRITERIA A-F)

UNIT SCORING GUIDE – CATEGORY II (CRITERIA A-G)

UNIT SCORING GUIDE – CATEGORY III (CRITERIA A-F)

OVERALL SCORING GUIDE

Scoring Guides for Each Category

Unit Scoring Guide – Category I (Criteria A-F)	
3	At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C
2	At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C
1	Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C
0	Inadequate (or no) evidence to meet any criteria in Category I (A–F)

Unit Scoring Guide – Category II (Criteria A-G)	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

Unit Scoring Guide – Category III (Criteria A-F)	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

OVERALL SCORING GUIDE	
E	**Example of high quality NGSS design—**High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9)
E/I	**Example of high quality NGSS design if Improved—**Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7)
R	**Revision needed—**Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5)
N	**Not ready to review**—Not designed for the NGSS; does not meet criteria (total 0–2)