Combustion Reaction Unit- Why can we burn fuel to keep ourselves warm?

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Overview of the unit

The purpose of this unit is to engage students in figuring out why we can burn fuel to keep ourselves warm. Students investigate how substances change in combustion reactions as a result of the numbers and types of bonds formed by each atom, which is determined by the outermost (valence) electron states and electronegativity. They also investigate how bond breaking and bond making relates to the energy changes in the system of a chemical reaction. The net release or absorption of energy depends on whether the relative potential energy of the reactants is lower or higher than the products. This will be examined in the context of fuel burning, where energy is released from a combustion reaction and used to produce stable products that have less potential energy than the reactants (the fuel). In the form of fast moving molecules, energy is transferred to the surroundings resulting in an increase in temperature, which is what keeps us warm.

Performance Expectations (from the NGSS)
HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
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.

Overview of the 3-Dimensional components in the unit

Elements from NGSS	**Connections to this unit**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectations	How this unit builds toward the core ideas
HS-PS1-2 PS1.A: Structure and Properties of Matter • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. PS1.B: Chemical Reactions • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	Students learn about interactions of matter and associated energy changes at the atomic-molecular level by investigating combustion reaction. When fuel burns, the bonds of fuel and oxygen are broken, and rearranged into other types of bonds in the products of carbon dioxide and water. Energy is always required to break a bond, energy is released when a bond is made. The net change of energy within the

HS-PS1-4 PS1.A: Structure and Properties of Matter • A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. PS1.B: 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 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.	system is the result of energy differences between bonds that are broken and formed during combustion reactions of fuels. Energy is transferred between the system and surroundings. As a result of molecular collisions, an increase of kinetic energy of the molecules in the surroundings occurs. Thus, we feel warm when fuel is burned.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectations	How this unit builds toward the science and engineering practice
HS-PS1-2 Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Students explore the driving question " Why can we burn fuel to keep ourselves warm?", and construct and revise explanations based on valid and reliable evidence from a variety of sources (students' own investigations, models, theories and simulations) that explain the driving question.
HS-PS1-4 Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop a model based on evidence to illustrate the relationships between systems or between components of a system.	Throughout the unit, students develop, revise and use their models to answer the driving question.

Crosscutting concepts	
Crosscutting concept from the NGSS Performance Expectations	How this unit builds toward the crosscutting concept
HS-PS1-2 Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	Students learn that the observed patterns of chemical properties can provide evidence for explaining the outcome of a simple chemical reaction.
HS-PS1-4 Energy and Matter ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.	Students learn that during combustion reaction changes in energy and matter occur within the system and between system and surroundings.

Background for teachers

The focus of this 2-3 week unit will be on investigating changes that happen at the molecular level in combustion reactions. Students will use ideas they learned in the previous units related to valence electrons and electronegativity to explain and to model the numbers and types of bonds that each atom forms during combustion reaction. Students will also investigate energy transfer into or from a system of a chemical reaction to explain bond breaking and forming during the reaction.

To reach the targeted NGSS Performance Expectations, students are expected to understand the following ideas:

1. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. (prior knowledge).
2. The repeating patterns of this table reflect patterns of outer electron states. (prior knowledge).
3. 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.
4. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
5. Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and 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.

What students need to know in order to answer the driving question "Why can we burn fuel to keep ourselves warm?"

1. A fuel is any material that can be made to react with other substances (particularly oxygen) so that it releases energy.
2. General types of chemical fuels are solid fuels (e.g. wood, coal, coke, charcoal, etc), liquid fuels (petroleum, gasoline, ethanol, etc), and gaseous fuels (natural gas, hydrogen, propane, methane, water gas, etc).
3. Combustion reaction, commonly called burning, is a chemical reaction between a fuel (e.g. Hydrocarbons), and oxygen, usually atmospheric oxygen releasing energy in the form of light and heat, that produces carbon dioxide (CO_2) and water (H_2O).
4. Chemical bonds are sources of stored energy. Breaking a bond is a process that requires energy; creating a bond is a process that releases energy.
5. The combustion reaction is an exothermic reaction which is a net of release energy, because more energy is released to form the bonds than is used to break bonds.

What students need to know in order to explain the phenomena of burn fuel to keep ourselves warm?

1. When fuel burns, it undergoes a chemical change during which products react to form new substances with different properties, and the changes are irreversible. For the combustion reaction of hydrocarbons, usually, the products are carbon dioxide (CO_2) and water (H_2O).
2. Energy was added at the beginning to break the bonds of the fuel and oxygen, and energy was released after the bonds of carbon dioxide (CO_2) and water (H_2O) formed.
3. The form of light and heat can be used as evidence to show the energy was released to the surroundings when the fuel burned.
4. The net energy change because energy released is greater than the energy used to break bonds in the reactants, and the net energy change is therefore positive.
5. Since the energy released from the burned fuel heated the air, the temperature around us is higher than our body, making us feel warm.

Prerequisite Knowledge for students

- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. (prior knowledge).
- The repeating patterns of this table reflect patterns of outer electron states. (prior knowledge).

Lesson 1 Why can we burn fuel to keep ourselves warm?

Lesson-level Driving Question
Why can we burn fuel to keep ourselves warm?

Lesson summary
In the first lesson, students experience the anchoring phenomenon and are introduced to the driving question. They engage with the anchoring phenomenon in which they experience that they feel warmer when they burn a matchstick or a paper. The purpose of this for students is to access their prior knowledge and to encourage them to share their ideas and generate questions related to the phenomenon and driving question. Students work in small groups to generate questions related to the driving question, categorize them and share them with other students to produce the Driving Question Board.

Lesson-level learning goal
Students make and use observations of fuel burning to ask questions and develop initial models related to energy and matter about why can we burn fuel to keep ourselves warm in the winter.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
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 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.	**Energy and Matter** ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.	**Asking questions** Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. **Develop a model** 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 figure out that when they burn the fuel they feel warm (or hot) because energy is transferred to the environment.	**Look for students** using observations of phenomena presented to ask questions and develop initial models related to energy and matter when fuel burned.

Evidence statement
Students use observations of phenomena to ask questions related to why burning fuel keeps us warm. Students' questions may include ideas related to how energy is involved in burning fuel; where the energy comes from; what fuel is made of (matchstick, paper, natural gas, and so on), products of the combustion reaction; what happens to fuel when it burns; the properties of reactants and products of the combustion reaction. Student initial models include representations of fuel and matter before and after fuel burned.

Connection to other lessons in unit
In the first lesson, students connect their prior knowledge and experiences about burning fuel to what they already know about combustion reactions. Most students should be able to recall a time when they felt warmer when there was fuel burning.

Materials and Preparation

Group materials (per 2-4 student group)-
- Dry hand towels
- Matchsticks
- 500 ml glass beaker

Whole class materials-
- Sticky notes
- Driving question board (bo be used in all following lessons)
- Markers

Safety guidelines

Basic laboratory safety guidelines. Heat protection gloves and protective glasses should be used by all students. Goggles need to be worn and long hair tied back. No loose clothing, etc.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
20	1.Introduction to the unit and experiencing the anchoring phenomenon • Group lab: use burning matchstick to light up the piece of towel in a beaker; • Introduce unit driving question; • Have students share and discuss their experiences.	Whole class/ Small groups

20	2. Developing and categorizing questions related to the driving question ● Have each student to write at least two questions on separate sticky notes; ● Have students group and category similar questions.	Small groups
15	3. Sharing questions and producing the Driving Question Board ● Whole class discussion: sharing categories and questions; ● Place all questions on the Driving Question Board ● Have students' questions be answered during the unit.	Whole class
30	4. Developing initial models to describe what happens when a fuel burns. ● Have students develop an initial model to describe what happens when a fuel burns; ● Walk around and ask each group questions to support students in drawing a model; ● Have students share their models and explain it.	Small groups
5	5. Wrap up: Revisiting Driving Question Board and developing Activity Summary Board ● Class revisits the unit driving question; ● Place answers to Activity Summary Board (ASB) related to the questions in DQB; ● Share out and add new questions to DQB; ● Remind the investigation in the next lesson.	Whole class

The driving question for this Investigation on **combustion reaction** is, ***Why can we burn fuel to keep ourselves warm?*** Post this question prominently in the room during the enactment of the unit. Include the Driving Question Board activity in the first lesson, and make sure it is addressed and reviewed in each lesson, together with the Activity Summary Board. For a detailed description of the Driving Question Board and the Activity Summary Board- see this DQB folder and this article Touitou et al., 2018.

Learning Sequence

Lesson Component 1: Introduction to the unit and experiencing the anchoring phenomenon

1. Each group receives a 500ml beaker, a few matchsticks and a dry hand towel. Place on a dry hand towel in the 500ml beaker. Have each student light a matchstick, hold it for a second or two and then use the burning matchstick to light up the piece of towel into a 500ml beaker. After the towel burns, have students touch the surface of the beaker

carefully after the towel burned. Ask students to observe and describe the phenomena, and their feelings when holding the matchstick and the surface of the beaker, directing them to think about what is happening to the towel and matchstick when they burn.

2. Introduce the driving question by asking students to share with a partner (turn and talk) experiences related to this phenomenon (i.e., cooking meals by burning natural gas, outdoor bonfire by burning wood, Alcohol burner in a chemistry lab). Ask a few students to share their experiences.
3. Conclude by explaining that in this unit we will investigate the driving question "Why can we burn fuel to keep ourselves warm?"

Tips for teachers- note on discussions

Discussions play an important role throughout this curriculum. In order to get students to share ideas and engage in lively discussions, it is important to set a tone that all ideas are important. The following types of questions can be used throughout all these discussions to encourage a variety of students to share their thoughts.

Questions to support building classroom community:

- *Who else has a different idea or description?*
- *Who else has a similar idea or description?*
- *Who agrees or disagrees with that idea? Explain.*
- *What questions could we ask or investigate to sort out the differences in people's ideas?*

Lesson Component 2: Developing and categorizing questions related to the driving question

1. In groups of 3-4 students, ask each student to write at least two questions related to their experience and their driving question. Students can either write them in their notebooks or on separate sticky notes.
2. Students share their questions in their small group. Tell students to group similar questions together. Ask students to develop categories for each group and explain their grouping. Possible categories that may emerge are type of fuel, atomic compositions of fuel, chemical structure of fuel, products of combustion reactions, energy transfer, effects on the temperature of our body.

Differentiated instruction suggestions

Not all students are accustomed to coming up with their own questions and categorizing questions. Have some questions and categories prepared in advance for groups that are struggling with this task, and have students engage with thinking about what type of knowledge is required for answering these questions.

Lesson Component 3: Sharing questions and producing the Driving Question Board

1. In whole class discussion, have students share their categories and questions. Place category and associated questions on the Driving Question Board. For each category, all

questions that are related should be placed in it. All questions should be categorized and placed on the Driving Question Board.

2. Tell the students that some of their questions will be investigated during the unit, and that they will constantly refer back to the Driving Question Board every lesson to keep track of which questions were addressed. Also mention they can add more questions anytime something new interests them in the lesson.
3. Students' questions will be part of the driving question board that will accompany the entire unit.

Lesson Component 4: Developing initial models to describe what happens when a fuel burns

1. Look for a similar question or just add "what happens when fuel (for example, paper) burns, and why does it make us feel warm?" to the list. Tell students they will develop a drawing (initial model) using their experience and observations from burning paper using matchsticks to explain the question. Students' drawing should describe what happens when a fuel burns. Discuss components that might be included in their model. Students should draw their models on a mini whiteboard or large sheet of paper so they can be shared with others.

Differentiated instruction

*As this is an initial model, allow students to express **their ideas** rather than pressing for accurate representations. Some students may have particle models and others may represent the phenomena at a macro level. Ask students to describe how their model explains the phenomena. Support students in asking each other questions about their models and identifying ways to communicate their ideas clearly. (labels, keys and other conventions)*

2. Walk around and ask each group questions to support students in drawing a model that provides causal explanation rather than description of observable components related to what happens:
    a. How does your model answer the question "what happens when the fuel (paper) burns, and why does it make us feel warm?"
    b. How are you showing the relationship between the parts/components that you have drawn?
3. Students should share their model with a partner or another group and explain it. Afterwards, students should either revise their own model based on peer feedback, or develop a group model.

Supporting student modeling

Use teacher talk moves to support students in sharing, expanding and clarify their own thinking about using models. During this discussion, stress that a model is not a literal translation of the phenomenon/event but rather an abstraction that explains the event/phenomenon. Students shouldn't focus on drawing the best looking hand, but rather on what's happening, or the relationship between the objects during evaporation.

Students should be encouraged to use their imaginations about how best to represent their "model". You can say that later on in the unit you will be more clearly defining what you are looking for in a model, but for now it is totally up to the students to decide. Additional support for the practice of modeling can be found here.

Lesson Component 5: Wrap up: Revisiting Driving Question Board

1. Class revisits the unit driving question. Students share their initial models that might help to answer the driving question.
2. Any questions answered from the driving question board should be (physically moved to the activity summary board, ASB) alongside a short description about the "big ideas" students figured out. (if most models included energy this might be a "big idea" that could be added to the ASB)
3. Students also share out any new questions they have about combustion reaction or related to the driving question. These new questions will be added to the driving question board (DQB).
4. Remind students that in the next lesson they will be investigating the driving question further.

Lesson 2 What happens to the fuel and the surroundings when the fuel burns?

Lesson-level Driving Question
What happens to the fuel and the surroundings when the fuel burns?

Lesson summary
In this lesson, students explore changes in observable physical properties and energy when a fuel burns. Observable physical properties include color, states, flash point…) of the substances and the accompanying changes in the temperature of the surroundings. Students observe teacher's demonstrations and collect data related to the physical properties of substances before and after fuel burning. They then analyze and interpret data to explain that new substances with different physical properties are produced, and energy is transferred to the surroundings when the fuel is burned.

Lesson-level learning goal
Students analyze and interpret data to gather evidence that the substances and the surroundings changed inevitably when the fuel burned.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
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 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. **PS1.B: Chemical Reactions** ● The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	**Pattern** Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	**Analyze and interpret data** Analyze data in order to make valid and reliable scientific claims.
Students figure out that new substances with different properties are produced, and energy is transferred to the surroundings when the fuel burned.	**Look for students** collecting, analyzing and interpreting data from the demonstrations to use as	

	evidence to claim the substances and the surroundings changed when the fuel burned. Student evidence is based on the changes in properties observed during fuel burning (color, status, chemical composition, flash point…) .

Evidence statement

Students make observations of different kinds of fuel burning, and collect data related to the changes of substances before and after the combustion reaction. Students analyze and interpret data using evidence from their observations to find patterns to explain that new substances with different properties are produced, and energy is transferred to the surroundings when the fuel burned.

Connection to other lessons in unit

In the previous lesson, students are introduced to the driving question and anchoring phenomena related to why we feel warmer when fuel burns. In this lesson, students collect and analyze data to be used as evidence to suggest that there were some other substances produced during burning as based on changes in observed properties of materials. Students also investigated energy changes during the process of burning fuel.

Materials and Preparation

Per student:

- Lesson 2 activity sheet

Safety guidelines

Basic laboratory safety guidelines.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Review the Driving Question Board ● Remind students the driving question and the phenomena in the previous lesson; ● Introduce the lesson driving question and investigation.	Whole class
5	2. Introduce the types of fuels ● Introduce fuels commonly used in everyday life;	Whole class

40	3. Collecting and analyzing data about combustion reactions ● Discuss with the students about the investigation of what happened to the fuel and the surroundings when fuel burns. ● Assign students lesson 2 activity sheet. ● Students further observe and describe the six different types of fuel burn. ● Students group and discuss the fuel based on their properties. ● Students make predictions about each fuel burning.	Whole class/Individual/ small group
10	4. Discussing the changes of fuel and surroundings ● Students think about whether all fuels react in the same way when they burn. ● Students share their findings with the whole class and further think about the changes that happen with the fuel and the surroundings. ● Students discuss possible products of burning fuel and energy changes.	Whole class/small group
5	5. Wrap up-Summarize the lesson using the Activity Summary Board ● Revisit the Activity Summary Board. ● Remind students of the changes they notice such as ash, smoke, fog, light or sound given off, etc.	Whole class

Learning Sequence

<u>Lesson Component 1: Review the Driving Question Board</u>

1. Remind students of the driving question and the phenomena they experienced in the previous lesson. Review the DQB and tell the students that today they will start investigating some of the questions they came up with that are related to the driving question.
2. Start the lesson by asking students the question: Why do you feel warm or hot when you were burning fuel? What happens to the substances and the surroundings when fuel burns? Why do you need air for the fuel to burn? (you could do a turn and talk or a whole group discussion).
3. Explain that in today’s lesson, they will investigate what changes happen to the fuel when it burns.

<u>Lesson Component 2: Introduce the types of fuels</u>

1. Introduce fuels commonly used in our daily life: fuels are substances,usually but not limited to Hydrocarbons,that can burn. In particular, Hydrogen gas and Coal can be also treated as fuels. (NOTE: hydrocarbon is a compound made of hydrogen and carbon atoms. Hydrocarbons are substances that make up gasoline and natural gas. The states of fuels vary, can be solid fuels (e.g. wood, coal, peat, dung, etc); can be liquid fuels (gasoline, ethanol, etc), and also can be gaseous fuels (such as hydrogen, methane, coal gas).

<u>Lesson Component 3: Collecting and analyzing data about combustion reactions</u>

1. Discuss with the students that in the next couple of lessons, they will investigate what happened to the fuel and the surroundings when fuel burns. Specifically, they will investigate how the products form, and energy changes that happen during the combustion fuel.
2. Before the teacher demo of combustion reactions, Lesson 2 activity sheet will be assigned to each student. Teacher asks students to go through the activity sheet, and record observations for each demo when the teacher shows the videos.
3. Teachers will provide students with six types of fuel (candle, alcohol, wood, natural gas, gasoline, and charcoal), and let students predict what will happen when these different fuels burn. Will the burning process look similar to what they observed when burning the towel and matchstick? And why? Students will further observe combustion of those fuels (gasoline and natural gas will be shown as video), and describe the observations focusing on changes in properties (color and state) in their lesson 2 activity sheet. They will also use the information provided by the teacher to describe the flash point and chemical composition of those fuels in their sheet.
4. After recording the observations for each fuel, students will be asked to group the fuel based on observed properties. Have students share their grouping and discuss in small groups.
5. After observation of those fuels, the teacher asks students to make predictions about each fuel burning, and later show the videos of what happens when those fuels are burning. The videos are linked on these lesson 2 slides. Ask students to pay careful attention to each video, and record observations in their lesson 2 activity sheet. Have students share their observations and discuss in small groups any changes they notice when the fuel is burning.

Lesson Component 4: Discussing the changes in the fuel and surroundings

1. Ask students to think about whether all fuels react in the same way when they burn? What differences and similarities do they notice from the data they collected? Have students discuss in small groups, and reach a group result.
2. Ask each group to share their findings with the whole class, and lead students to further think about the changes that happen with the fuel and the surroundings.
3. Discuss possible products of burning fuel, and the associated energy changes. How and why it happened?

Lesson Component 5: Wrap up-Summarize the lesson using the Activity Summary Board

1. Revisit the Activity Summary Board to identify what students were able to figure out in this lesson. Press students to think about how we can figure out what new substances formed? Are the products of the combustion reaction the same substances as starting materials or not?
2. Remind students of the changes they notice such as ash, smoke, fog, light or sound given off, etc. How is it related to energy changes? Ask students to think about what new questions need to be asked to figure out.

Lesson 3 What are the products and the associated energy changes when a fuel burns?

Lesson-level Driving Question
What are the products and the associated energy changes when a fuel burns?

Lesson summary
In this lesson, students investigate the products of combustion reaction and the energy changes during the process. They design an experiment, make observations and collect data about the properties of the products and the temperature changes of the surroundings. They further use this data as evidence to construct explanations about what products form and how energy changes when fuel burns based on the chemical properties of the substances.

Lesson-level learning goal
Students construct explanations using evidence to explain the changes of chemical substances before and after the fuel burns based on the patterns of chemical properties of the substances.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
PS1.B: Chemical Reactions • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	**Pattern** Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	**Construct Explanation** Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

Students figure out that the products of the reaction of a fuel (e.g. candle) burning can be predicted and explained using chemical properties of the elements involved.	**Look for students** using the properties of products to construct an explanation that candle reacted with oxygen in the air to form CO_2 and H_2O when the candle burned. Students should support their explanation using evidence based on the changes of chemical substances before and after burning, and the associated temperature changes as measured by thermometer. *Revise models based on evidence from their investigation. Look for student models showing the matter and energy changes before and after the candle burning.*

Evidence statement
Claim: Students should make a claim that when a candle burns, it reacts with the oxygen in air and forms CO_2 and H_2O.
Evidence: Students provide appropriate evidence that supports the claim that the candle reacted with oxygen in air to form products of the combustion reaction. Evidence of forming CO_2 as a product of the combustion reaction include milky appearance of the limewater when added to the beaker containing the candle. Evidence of forming water as a product of combustion reaction include water collected under the cover and on the wall of the dry covered beaker containing burning candle.
Reasoning: Students provide reasoning for the claim by stating that we can use the chemical properties of substances before and after the candle is burnt to determine what products formed.

Connection to other lessons in unit
In Lesson 2, students made observations of different fuels burning, collected, analyzed and interpreted data as evidence to find a pattern that there were some other substances produced and energy transferred when the candle burned. In this lesson, students investigate and explain what substances formed and how the temperature of the surroundings changed when candle burned.

Materials and Preparation
Group materials (per 2-4 student group)-
- Two 1000ml beakers
- Two short white candles
- Matchsticks
- Limewater
- One thermometer

Per student
- Lesson 3 activity sheet

Safety guidelines

Standard laboratory safety guidelines when experiment. Heat protection gloves and protective glasses should be used by all students.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Introduction-Review the Driving Question Board and observations from previous lessons ● Revisit the DQ Board and discuss student ideas about the changes of fuel and the surroundings, and the unit driving question. ● Encourage students to think about how do we know what the fuel reacted with and what we formed when fuel burned. ● Students make and write predictions about the reactants and products of fuel burning. ● Let students know that today's lesson, thy will investigate the fuel burning reaction.	Whole class
30	2. Group activity- investigating the combustion of candle ● Introduce the experiment and divide students into small groups. ● Investigation 1: Place a burning candle in a Jar. ● Investigation 2: Uncover and cover a burning candle in a dry beaker ● Have students record their observations in Lesson 3 Activity Sheet. ● Show students' evidence. ● Students discuss and share their evidence.	Small group
20	3. Constructing an explanation using evidence to make sense of the changes of matter and energy transfer when the fuel burned. ● Students think again about the lesson's driving question. ● Students write and support their claims individually to answer the driving question in Lesson 3 Activity Sheet. ● Students share, compare and give feedback about explanation in group. ● Students revise their explanations based on feedback.	individual/whole class
5	4. Wrap up-Summarize the lesson using the Activity Summary Board ● Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out. ● Refer to the Activity Summary Board. ● Transfer the questions from the DQB to the ASB.	Whole class

Learning Sequence

Lesson Component 1: Introduction-Review the DQB and observations from previous lessons

1. Revisit the DQ Board and discuss student ideas about the observations made in Lesson 2 of the changes of fuel and the surroundings, and the unit driving question. Support students' discussion of the similarities and differences between the combustion of different fuels.
2. Encourage students to think about how do we know what the fuel reacted with and what we formed when fuel burned. Can we get any evidence to support our claims? How can we use evidence to support our claim about the products of burning fuel ? (you could do a turn and talk or a whole group discussion).
3. Students may use prior knowledge related to the conservation of atoms to predict that the fuel reacted with O_2 in the air to produce $CO_2(g)$ and $H_2O(g)$. Have students think about how do you know that? Any evidence to support your claim? Have students write their predictions in Lesson 3 Activity Sheet.
4. Explain that in today's lesson, they will investigate what reacted with fuel, and what formed after the fuel burned.

Lesson Component 2: Group activity-investigating the combustion of candle

1. Introduce the experiment and divide students into small groups. Each group will conduct their own experiment as follows. Before starting to do investigation, teacher introduces Lime water for students that Lime water is the common name for a dilute aqueous solution of calcium hydroxide, $Ca(OH)_2$. Limewater is clear and colorless, with a slight earthy smell and a bitter taste. Limewater can test for the presence of carbon dioxide gas.
2. Investigation: Uncover and cover a burning candle in a dry beaker
   a. Place a short white candle (around 5cm height) on the center of a clean and dry beaker (1000ml).
   b. Use a thermometer to record room temperature.
   c. Light the candle, use another beaker (1000ml) to cover the beaker with the burning candle. Have students observe very carefully the candle and the beaker.
   d. Students may see the flame of the candle become smaller. When that happens, they should uncover the beaker observe and record.
   e. Have students cover and uncover the beaker with the burning candle several times, and ask them to observe and record.
   f. Have students cover the beaker with the burning candle partially so that the candle can keep burning for at least 5 min. Have students observe the bottom and the walls of the beaker carefully, and record.
   g. Add about 20ml Lime Water into the beaker carefully. After at least 3 minutes, have students observe the lime water very carefully.
   h. At the end of the experiment, carefully blow out the candle. Use a thermometer to record the temperature inside of the beaker. When the beaker cools down, dispose of the water and clean the lab station.
2. Have students record their observations in Lesson 3 Activity Sheet. Have students think about what evidence they can use to figure out what substances react with the candle's flame, and what other evidence can be used to figure out what substances were formed when the candle burned.
3. Students evidence should be included:
   a. Burning candle created light and heat;

   b. When we cover the beaker, the flame became smaller and eventually went out if covered fully; when we uncover the beaker, the candle flame became much brighter.
   c. When we covered the beaker partially, after at least 5min the beaker inside became foggy (suggest time: at least 5min), and water was seen at the bottom and on the walls of the beaker.
   d. When we added Lime water into the beaker (suggest time: at least 3 min) , the lime water turns milky.
4. Ask students discuss in each group, and share their evidence with the whole class, record other students' observations and questions in Lesson 3 Activity Sheet.

Lesson Component 3: Constructing an explanation using evidence to make sense of the changes of matter and energy transfer when fuel burned.

1. After students' discussion, ask students to think again about the lesson's driving question: how do we know what we formed and the energy transferred when fuel burned based on the investigation of burning candle?
2. Have students write claims individually to answer the driving question in Lesson 3 Activity Sheet, and use evidence from the investigation to support their claims. Construct an explanation using evidence to explain what happened at the molecular level when the candle burned.
3. Students' explanations should include:
   a. In the combustion of candle, the candle reacted with oxygen in the air to produce water and carbon dioxide. We know this based on observation of water collected on the walls of the beaker, and test of lime water that indicated production of carbon dioxide.
   b. Burning candle released energy as flame and light so that the candle melted, and the temperature of the beaker increased.
4. Students will share their explanation in their group, and will compare and give feedback for explanations.
5. Have students use the feedback from their discussion to make revisions, and share with the class.

Lesson Component 4: Wrap up-Summarize the lesson using the ASB.

1. Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out in order to answer the driving question: How do we know what we formed when the fuel burned?
2. Refer to the Activity Summary Board: Which questions were addressed in the lesson? What did we do in the lesson? What did we learn?
3. Transfer the questions that were addressed in the lesson from the DQB to the ASB and complete the rest of the row. (what did we do? What did we learn?)

Lesson 4 How does energy change when the molecules of a fuel are broken and formed during a combustion reaction?

Lesson-level Driving Question
How does energy change when the molecules of a fuel are broken and formed during a combustion reaction?

Lesson summary
In this lesson, students use the simulation to explore the interaction between atoms and energy changes that occur when a chemical bond forms using examples of simple molecules (e.g.H_2). Students apply their knowledge of electric forces and use the potential energy curve as evidence to model the process of forming a chemical bond and explain associated energy changes as related to distance between two interacting atoms.

Lesson-level learning goal
Students develop models to explain why a stable molecule has less energy than the same set of atoms separated.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
PS1.A: Structure and Properties of Matter • 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.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.	*Developing and Using Models* • Develop, revise, and/or use model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
Students figure out that the atoms that make up a stable molecule give off energy when they form the molecule.	**Look for** students developing models based on evidence from their investigation. Look for Ss models showing how two atoms interact with each other as the distance between them changes.	

Evidence statement
Student models should describe how two atoms (in this example, hydrogen atoms) interact with each other as the distance between them changes from far away to very closely using the evidence from the simulation.

Model components should include: two hydrogen atoms with nucleus and electrons; electrons modeled as cloud or point charge, changes in the position of electrons (point charge or cloud) as distance between nuclei changes.

Model should show the relationship between model components: the electron clouds of two hydrogen atoms are the same size; interactions between nuclei of the two hydrogen atoms, nuclei and electrons, electrons of both atoms.

- When the two atoms are far away, there is no interaction between their nuclei and electrons, and potential energy of the system does not change.
- As the two atoms get closer together, attractive force is generated between electron clouds of one atom and the nucleus of the other atom. There is also repulsive force between nuclei of the two atoms, but it is smaller than the attractive force between nuclei and electrons, and therefore overall force is attraction. As the distance decreases, attractive force between the two opposite charges increases, and the potential energy of the system decreases.
- At a certain distance (different for different combinations of atoms) the attractive force between electrons and nuclei, and repulsive force between nuclei of the two atoms balance out. Potential energy of the system is minimal because attractive and repulsive forces balance out. At this distance atoms are at its most stable state due to balance of electric forces and minimum potential energy associated with this relative position of atoms. It is at this distance that a chemical bond is formed.
- If the two atoms continue moving closer, repulsive force between nuclei and electron clouds increases rapidly, causing potential energy of the system increase too. The overall net force is repulsion. Associated large potential energy of the system causes this arrangement to be highly unstable. The atoms repel.

Connection to other lessons in unit
In previous lessons , students conducted an experiment and developed explanations related to what products form when fuel burns, and how energy changes during the process based on the chemical properties of the substances. In this lesson, students use the simulation to investigate why we need to add energy to fuel to cause it to burn. To answer this question, students investigate the process of forming and breaking a chemical bond, and associated energy changes using simulation focused on how two atoms interact with each other at a distance. They develop models based on evidence from the simulation to help them make sense of what happens during the process of forming and breaking a chemical bond.

Materials and Preparation

Lesson 4 Activity Sheet

Safety guidelines

Basic laboratory safety guidelines.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Warm-up-Review the Driving Question Board and Activity Summary Board ● Review the DQB and revisit questions on DQ board related to the changes that happen during burning of fuel, reaction with oxygen, and energy transfer. ● Introduce today's lesson driving question and have students turn and discuss their questions. ● Have students think about how atoms can come together to form a molecule and energy change. ● Tell students that today they will investigate how atoms interact to form simple molecules using simulation.	Whole class
30	2. Simulation of the same type of atoms (H_2) ● Introduce the simulation of interactions on Concord website. ● Introduce the potential energy curve to students. ● Have students look at the diagram (potential energy curve) and use the diagram to explain what happens to the interactions of two atoms getting closer and closer.	Individual
15	3. Develop and revise models of two H atoms in a molecule ● Have students apply their knowledge of electric forces and use the potential energy curve as evidence develop a model to describe what drives formation of a chemical bond. ● Students draw their models and write explanations in the Lesson 4 Activity Sheet.	individual/whole class
10	4. Sharing and discussing models of two H atoms interact in a molecule ● Have students think about how their models account for their observations and explain why do we need to add energy to start the fuel burning. ● Sharing several models with the class.	Whole class
5	5. Wrap up-Summarize the lesson using the Activity Summary Board ● Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question. Refer to the Activity Summary Board.	Whole class

Learning Sequence

<u>Lesson Component 1: Warm up-Review the Driving Question Board and Activity Summary Board</u>

1. Review the DQB and revisit questions on DQ board related to the changes that happen during burning of fuel, reaction with oxygen, and energy transfer. From the ASB, students revisit the findings in lesson 3. Specifically, they have determined that burning fuel releases energy to the surroundings. Have students think about: if burning fuel releases energy, why do we need to add energy (light fuel) to the fuel for it to start burning?
2. Introduce today's lesson driving question: How energy changes when the molecule of a fuel is broken and formed during a combustion reaction? Have students think about the answer using their prior knowledge and experience about atomic structure and energy changes at the atomic level. Have students turn and discuss their questions, allow students to share their responses.
3. After discussion, have students think about how atoms can come together to form a molecule? How do atoms interact with each other within a molecule? How does energy change when atoms interact to form a molecule?
4. Explain that in today's lesson, they will work with simulations to investigate how atoms interact to form simple molecules, and develop a model to describe and explain the process of forming and breaking a bond.

Lesson Component 2: Simulation of the same type of atoms

1. Introduce the simulation of interactions on Concord website. Using molecules made of the same type of atoms (e.g.H_2), ask students to conduct the simulations following instructions below:
    a. Have students to drag the two atoms (e.g. H_2) far away and describe how the two atoms interact when they are far away. Are there any attractive/repulsive forces present? How does the energy of the system change?
    b. Next, have students put the two atoms closer and closer. Ask them to describe how interactions between atoms change. How does the energy of the system change as the two atoms get closer together? Students should do the space filling visualization first, and then do the electron cloud visualization.
    c. Observe and record the results from the simulation in the Lesson 4 Activity Sheet.
2. Introduce the potential energy curve to students. [Note for teacher: Potential Energy Curve: The energy of a system of two atoms depends on the distance between them. At large distances the energy is zero, meaning "no interaction". At distances of several atomic diameters attractive forces dominate, whereas at very close distances the force is repulsive, causing the energy to rise. The attractive and repulsive interactions are balanced out at the distance between the atoms that corresponds to the minimum potential energy of the system on the potential energy curve. Plots that illustrate this relationship are quite useful in defining certain properties of a chemical bond.The internuclear distance at which the potential energy minimum occurs defines the **bond length**. This is more correctly known as the *equilibrium* bond length, because thermal motion causes the two atoms to vibrate about this distance. In general, the stronger the bond, the smaller the bond length.]
3. Have students look at the diagram below (potential energy curve) and use the diagram to explain what happens to the interactions of two atoms getting closer and closer.

Lesson Component 3: Develop and revise models

1. Have students apply their knowledge of electric forces and use the potential energy curve as evidence develop a model to describe what drives formation of a chemical bond. Follow the instructions below to help students navigate the simulation Use the evidence from the simulation, develop a model to describe how two hydrogen atoms interact to form a hydrogen molecule. Have students use the model they draw to explain whether a molecule or the set of atoms are more stable and why. Make sure the model shows the interaction between two hydrogen atoms that are far away, and as they are moving closer to the equilibrium position (balanced forces and minimal energy), and closer (past equilibrium position).

- Students model should describe how two atoms (in this example, hydrogen atoms) interact with each other as the distance between them changes from far away to very closely using the evidence from the simulation.
- *Model components* should include: two hydrogen atoms with nucleus and electrons; electrons modeled as cloud or point charge, changes in the position of electrons (point charge or cloud) as distance between nuclei changes.
- *Model should show the relationship* between model components: the electron clouds of two hydrogen atoms are the same size; interactions between nuclei of the two hydrogen atoms, nuclei and electrons, electrons of both atoms.
    - When the two atoms are far away, there is no interaction between their nuclei and electrons, and potential energy of the system does not change.
    - As the two atoms get closer together, attractive force is generated between electron clouds of one atom and the nucleus of the other atom. There is also repulsive force between nuclei of the two atoms, but it is smaller than the attractive force between nuclei and electrons, and therefore overall force is attraction. As the distance decreases, attractive force between the two opposite charges increases, and the potential energy of the system decreases. Student models should show electron cloud/electrons as point charges move towards the region between the two atoms as atoms move closer to each other due to attractive forces.
    - At a certain distance (different for different combinations of atoms) the attractive force between electrons and nuclei, and repulsive force between nuclei of the two atoms balance out. Potential energy of the system is minimal because attractive and repulsive forces balance out. At this distance atoms are at its most stable state due to balance of electric forces and minimum potential energy associated with this relative position of atoms. It is at this distance that a chemical bond is formed.
    - If the two atoms continue moving closer, repulsive force between nuclei and electron clouds increases rapidly, causing potential energy of the system increase too. The overall net force is repulsion. Associated large potential energy of the system causes this arrangement to be highly unstable. The atoms repel.

2. Students draw their models and write explanations in the [Lesson 4 Activity Sheet].

<u>Lesson Component 4: Sharing and discussing models</u>

1. Have students think about how their models account for their observations and explain why do we need to add energy to start the fuel burning.
2. Sharing several models with the class (H_2), have the students discuss their drawings. Students should ask any questions they have about a drawing.
    a. Suggestions for discussion questions:

i. What similarities are there?
ii. What differences are there?
iii. What evidence supports their drawing?
iv. Can your model account for the phenomena they experienced in class?

3. From this discussion, we are looking to foreground the idea that it takes energy to disrupt attractive interactions between two atoms and that when heat (thermal energy) is added to a molecule, energy is transferred to the system of two atoms. This transfer of energy will cause the distance of two atoms in a molecule to increase, which leads to greater potential energy of the system of the two atoms, and the attractive forces between the two atoms become smaller. We experience this increase potential energy as the rearrangements of atoms into new molecules (e.g. no longer present as H_2).

Lesson Component 5: Wrap up-Summarize the lesson using the Activity Summary Board

1. Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question. Refer to the Activity Summary Board: Which questions were addressed in the lesson? What did we do in the lesson? What did we learn?

Lesson 5 How can we compare different types of chemical bonds during combustion reactions?

Lesson-level Driving Question
How can we compare different types of chemical bonds during combustion reactions?

Lesson summary
In this lesson, students review the model of two hydrogen atoms interacting to form a bond (two of the same type of atoms), and investigate the simulation (H and O) (two different types of atoms) to draw a model to describe how one hydrogen atom and one oxygen atom interact with each other at a distance. They then use the model to explain why water is more stable than separate oxygen and hydrogen atoms. Students continue to investigate how different combinations of atoms interact when forming a chemical bond to further develop their models of bonds focusing on representation of chemical bonds.

Lesson-level learning goal
Students develop and use models to explain the similarities and differences in interactions between different types of atoms and the same types of atoms when they form bonds.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
PS1.A: Structure and Properties of Matter • 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.	*Pattern* • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena	**Analyzing and Interpreting Data** • Analyze data in order to make valid and reliable scientific claims. ***Developing and Using Models*** • Develop, revise, and/or use model based on evidence to illustrate and/or predict the relationships between systems or between components of a

		system.
Students figure out that the types of chemical bonds depends on the electronegativity of atoms	**Look for students** identifying the similarities and differences in how different combinations of atoms interact to form chemical bonds to further develop their models of chemical bonding and representation of chemical bonds.	

Evidence statement

- Students develop and revise model to show how two different types of atoms (H and O) interact as distance between them decreases and increases:
  - Model components: one oxygen atom with nucleus and electrons, one hydrogen atom with nucleus and electrons; electrons represented either as point charges or as electron cloud.
  - Relationship between model components: the electron cloud of oxygen is bigger than electron cloud of hydrogen (electrons are more likely to move towards oxygen). Repulsive interactions between oxygen nucleus and hydrogen nucleus, attractive interactions between oxygen nucleus and electrons, hydrogen nucleus and electrons, repulsive interactions between electrons and electrons. The electron clouds of hydrogen and oxygen overlapped. There is a higher electron density in the region between the two atoms. Alternatively, if electrons are represented as point charges, they are shown to be located in the region between the two atoms.
  - The interaction between two atoms at a distance are modeled as attractive; as the distance of two atoms decreases, the attractive interaction become bigger, and potential energy of the system decreases. At the point where attractive and repulsive interactions balance out, the energy of the system is minimal. At this distance the chemical bond between oxygen and hydrogen forms. Chemical bond is represented as sharing of electrons between the two atoms forming a chemical bond by either showing the two electrons as point charges located in the region between the two atoms, or representing larger electron density in the region between the two atoms if electrons are modeled as clouds. If two atoms move closer, repulsive forces between nuclei and electron clouds become larger than attractive forces, and the potential energy of the system becomes very large, causing the two atoms to push away.
- Students use the simulation to compare models of chemical bonds between atoms of similar electronegativity (like H_2) and different electronegativity (like O-H). They use this information to explain the continuum of electric forces between atoms that results in different types of bonding between atoms:
  - Chemical bonds are the forces that attract atoms to each other to form molecules, bonding involves attractive interaction between the valence electrons of one atom and the nucleus of the other atom involved in forming a chemical bond. It is the sharing of valence electrons between the nuclei of the two atoms via attractive electric forces that constitutes the chemical bonds between the two atoms.

- Electrons within a chemical bond are not always shared equally between the two atoms. In other words, nuclei of atoms involved in forming a chemical bond might have different affinity for the electrons. Atoms of different elements have different affinity for electrons. This property is called electronegativity. Elements with higher electronegativity have higher attraction for electrons. Electronegativity increases going across and up the row.
- Depending on the magnitude of difference in electronegativity between elements that form a chemical bond, chemical bonds can be categorized as ionic bond (extremely polar), polar covalent bond, and nonpolar covalent bond. Elements with drastically different electronegativity values (like Na and Cl) form ionic bonds, where the shared electrons in a chemical bond are essentially transferred to more electronegative atom forming ions (Na^+ and Cl^-), Elements with moderate differences in electronegativity values (like H-H) form polar covalent bond, where shared electrons are shifted towards more electronegative atom creating partial negative charge around it (O), and partial positive charge around the less electronegative atom (H). Finally, elements with similar electronegativity values (H-H) for nonpolar chemical bonds, where electrons are shared equally between two atoms.

Connection to other lessons in unit

In lesson 4, students investigated the simulation and developed a model of the same type of atoms. In this lesson, students will think about: How do different atoms interact in a molecule? Are interactions between different types of atoms forming a bond similar of different to when the atoms of the same element is forming a bond? What are the differences and why? Then students will develop a model to show how different types of atoms interact in a molecule, and compare the similarities and differences of these two different scenarios. Based on the evidence from the simulation, students will use the model to explain different types of chemical bonds according to the electronegativity of elements.

Materials and Preparation

Per student:

Lesson 5 activity sheet

Periodic Table

Safety guidelines

Basic laboratory safety guidelines.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Review the Driving Question Board and Activity Summary Board • Review the DQB and ASB, revisit students' models of hydrogen atoms interactions in a Hydrogen molecule, and refer back about their models for describing how the two same hydrogen atoms interacted when the distance between them decreases.	Whole class

	• Students turn and discuss the question and share their response. • Tell students that today they will investigate how atoms of different elements interact to form a chemical bond.	
5	2. Simulation: Forming a chemical bond with different types of atoms (H_2O) • Have students investigate how oxygen atom and hydrogen atom interact with each other to form a chemical bond. • Students observe and record the results in Lesson 5 Activity Sheet. • Students look at the diagram (potential energy curve) from simulation, and use the diagram to explain what happens to the interactions of two atoms getting closer and closer.	Individual
10	3. Develop and revise models of two atoms interact • Students review the model of two hydrogen atoms interacting, and look at the simulation (H and O) to draw a model to describe how one hydrogen atom and one oxygen atom interact with each other to form a chemical bond. • Students use the model to explain why a set of hydrogen and oxygen atoms are more stable than separate O and H atoms. Developing and revising model to show how the two different types of atoms (H and O) interact as distance between them decreases. • Students draw their models and write explanations in the Lesson 5 Activity Sheet.	Individual
20	4. Comparison of the models of atoms interactions in a hydrogen molecule and in a water molecule • Students compare the model of two different types of atoms (H and O) with the model of the same type of atoms (H and H), have students find the similarities and differences of the two models. • Students discuss why the electron cloud distribution and size for H-O and H-H are different. • Students use the potential energy curve as evidence to explain the differences. • Students predict the model of the interaction of a sodium atom and a fluorine atom, and draw the model in Lesson 5 activity sheet, and compare the model with the two models (H and H, H and O).	Small group
30	5. Introduce different types of chemical bonds • Students come to a consensus about what factors drive the formation of a chemical bond. • Introduce different types of chemical bonds as a function of continuum of strength of electric interactions between the atoms involved to students.	Whole class

20	6. The similarities and differences among different types of chemical bonds ● Have students think about the difference in potential energy that they observed for H-H vs O-H. ● Students use the idea of chemical bond to explain why water is more stable than separate oxygen and hydrogen atoms. ● Addressing the lesson driving question.	Whole class/individual
5	7. Wrap up-Summarize the lesson using the Activity Summary Board ● Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question.	Whole class

Learning Sequence

Lesson Component 1: Review the Driving Question Board and Activity Summary Board

1. Review the DQB and ASB, revisit students' models of hydrogen atoms interactions in a Hydrogen molecule, and refer back about their models for describing how the two same hydrogen atoms interacted when the distance between them decreases. From the simulation and the modeling activity, students have made some predictions about how the same type of atoms interact to form a chemical bond. Connect with Lesson 4, in this lesson, have students think about: How do different atoms interact to form a chemical bond? What are the differences and why?
2. Have students turn and discuss the question, allow students to share their responses.
3. Explain that in today's lesson, they will continue working with the same simulation but this time they will investigate how atoms of different elements interact to form a chemical bond.

Lesson Component 2: Simulation of the different type of atoms (e.g. H_2O)

1. Simulation on forming chemical bonds between atoms of different elements(e.g.H_2O). Have students investigate how oxygen atom and hydrogen atom interact with each other to form a chemical bond.
2. Students observe and record the results in Lesson 5 Activity Sheet.
3. Have students look at the diagram (potential energy curve) from simulation, and use the diagram to explain what happens to the interactions of two atoms getting closer and closer.

Lesson Component 3: Develop and revise models of two atoms interact.

1. Have students review the model of two hydrogen atoms interacting, and look at the simulation (H and O) very carefully to draw a model to describe how one hydrogen atom and one oxygen atom interact with each other to form a chemical bond.
2. Have them use the model to explain why a set of hydrogen and oxygen atoms are more stable than separate O and H atoms. Students develop and revise model to show how the two different types of atoms (H and O) interact as distance between them decreases:
    i. Model components: one oxygen atom with nucleus and electrons, one hydrogen atom with nucleus and electrons; electrons represented either as point charges or as electron cloud.

ii. Relationship between model components: the electron cloud of oxygen is bigger than electron cloud of hydrogen (electrons are more likely to move towards oxygen). Repulsive interactions between oxygen nucleus and hydrogen nucleus, attractive interactions between oxygen nucleus and electrons, hydrogen nucleus and electrons, repulsive interactions between electrons and electrons. The electron clouds of hydrogen and oxygen overlapped.

iii. The interaction between two atoms at a distance are modeled as attractive; as the distance of two atoms decreases, the attractive interaction become bigger, and potential energy of the system decreases. At the point where attractive and repulsive interactions balance out, the energy of the system is minimal. At this distance the chemical bond between oxygen and hydrogen forms. If two atoms move closer, repulsive forces between nuclei and electron clouds become larger than attractive forces, and the potential energy of the system becomes very large, causing the two atoms to push away.

3. Students draw their models and write explanations in the Lesson 5 Activity Sheet. Sharing several models with the class, have the students discuss their drawings. Students should ask any questions they have about a drawing.

<u>Lesson Component 4. Comparison of the two models of atoms interactions in a hydrogen molecule and in a water molecule</u>

1. Compare the model of two different types of atoms (H and O) with the model of the same type of atoms (H and H), have students find the similarities and differences of the two models. Students may find that:
    a. The similarities between the two models: attractive and repulsive interactions follow and potential energy changes follow the same pattern: as the distance between two atoms decreases, attractive interactions become larger, and potential energy of the system decreases.
    b. At the distance where attractive and repulsive interactions balance out the potential energy of the system is minimal, and this is where the chemical bond between the two atoms forms, if the atoms continue moving closer, repulsive interactions increase, and potential energy of the system increases. Attractive interactions between nucleus of one atom and electron clouds of the other atom, repulsive interactions between nuclei and electron clouds of the two atoms.
    c. The differences between the two models: the clouds of electrons are not distributed evenly between H and O, electron density is shifted towards more electronegative O atom. the distances at which the attractive and repulsive forces between atoms are balanced out and the potential energy of the system is minimal is larger for H-O pair than for H-H pair; the potential energy of H-O is larger than the potential energy of H-H.
2. Ask students why the electron cloud distribution and size for H-O and H-H are different. Have students discuss in group, and share their explanations to the class. Students' answers may include: different sizes of atoms; the mass of atoms, or the core charges of atoms.
3. After discussion, have students apply their knowledge of electric forces and electronegativity, and use the potential energy curve as evidence to explain the

differences. Students may explain the differences that the electronegativity of oxygen is larger than hydrogen, result in oxygen atom is more likely to attract electrons from hydrogen atom; thus, the electron clouds of H-O are not even as H-H, but more likely at the oxygen side.

4. Have students predict the model of the interaction of a sodium atom and a fluorine atom, and draw the model in Lesson 5 activity sheet, and compare the model with the two models (H and H, H and O), and explain why. Ask students to discuss in groups and share their models with the class.

Lesson Component 5: Introduce different types of chemical bonds

1. After simulation and modeling, encourage students to come to a consensus about what factors drive the formation of a chemical bond: a chemical bond between two atoms forms when attractive interactions between the nuclei and valence electrons of adjacent atoms balance out repulsive interactions between nuclei and between valence electrons of the atoms. At this distance the potential energy of the system is minimal, and therefore the system is at its most stable state, which drives the formation of a chemical bond.
2. After discussion, introduce different types of chemical bonds as a function of continuum of strength of electric interactions between the atoms involved to students. Ask students how can we differentiate different types of chemical bonds, referring to the electron cloud distribution from the simulation.
    a. What does the electron cloud distribution of H_2 looks like? How can you use the idea of electronegativity to explain the distribution?
    b. What does the electron cloud distribution of H_2O looks like? How can you use the idea of electronegativity to explain the distribution?
    c. What does the electron cloud distribution of NaF looks like? How can you use the idea of electronegativity to explain the distribution?
3. According to the electron cloud distribution from the simulations the electronegativity of elements, chemical bonds can be categorized as ionic bond (extremely polar), polar covalent bond, and nonpolar covalent bond.
    a. H-H can be treated as nonpolar covalent bond since the outermost electrons can be found evenly in the system of two H atoms.
    b. H-O can be treated as polar covalent bond since the outermost electrons are more likely to be found around O than H.
    c. Na-F can be treated as ionic bond since the outermost electrons are most likely to be found around F, but seldom around Na.

Lesson Component 6- the similarities and differences among different types of chemical bonds

1. Have students think about the difference in potential energy that they observed for H-H vs O-H.
2. What is the difference in the amount of energy will need to be added to break a bond in H_2 compared to break a bond in H_2O, vs How does that relate to which compound is better to be used as fuel, H_2 or H_2O? use the idea of chemical bond to explain why water is more stable than separate oxygen and hydrogen atoms.
3. Make connections to other fuel types (like carbon-based, CH4 vs H2, etc.). Addressing the lesson driving question: what are the similarities and differences among different types of chemical bonds during combustion reactions?

Lesson Component 7: Wrap up-Summarize the lesson using the Activity Summary Board

1. Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question. Refer to the Activity Summary Board: Which questions were addressed in the lesson? What did we do in the lesson? What did we learn?

Lesson 6 How much energy do we need to add to the fuel for it to start burning?

Lesson-level Driving Question
How much energy do we need to add to the fuel for it to start burning?

Lesson summary
In this lesson, students experience the simulation of bond breaking and forming, analyze and interpret data to find the pattern about the energy change of the bond breaking and forming, and then construct an explanation to make a claim about how much energy should be added to the fuel to start burning.

Lesson-level learning goal
Students construct an explanation about how much energy should be added to the fuel to start burning.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
PS1.A: Structure and Properties of Matter • 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.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.	**Construct Explanation** • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
Students figure out that a stable molecule has less energy than the same set of atoms separated, we must provide at least this energy to break the bonds in a molecule.	**Look for students** constructing explanations using evidence from simulations to make a claim about how much energy should be added to the fuel to start burning**.**	

Evidence statement
Students' explanation should include the following aspects:

1) Claim: a stable molecule has less energy than the same set of separated atoms. At least the difference of the amount of energy should be added to break a chemical bond, and vice-versa, to form the same chemical bonds, the same amount of energy will be released.
2) Evidence(s): Energy is always required to break a bond; Energy is released when a bond is formed.
3) Reasoning: Bond energy (E) is the amount of energy required to break apart the atoms in a molecule. It is a measure of the strength of a chemical bond in a molecule. Energy is always required to break a bond, energy is released when a bond is formed.

Connection to other lessons in unit
Students have figured out why do we need to add energy to start burning the fuel in Lessons 5, in this lesson, they will use the evidence from the simulation about the bond breaking and forming to construct an explanation that how much energy do we need to light the paper to get start combustion.

Materials and Preparation

Lesson 6 Activity Sheet

Safety guidelines

Basic laboratory safety guidelines.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Review the Driving Question Board and Activity Summary Board ● Review the DQB and ASB, revisit students' models of different types of chemical bonds and the simulation focusing on forming a chemical bond between different types of atoms. ● Students turn and talk to discuss the questions. ● Tell students that today we explore simulations to investigate the bond breaking and forming in a molecule formed by atoms with similar and different electronegativities.	Whole class
20	2. Simulation of bond breaking and forming: online simulations of pull a polar/nonpolar molecule. ● Introduce the online simulations of pull a polar/nonpolar molecule. ● Have students use the simulation, and pull two atoms apart slowly as far as they can. ● Students use the data to explain how the energy of the system changes when breaking or forming a chemical bond.	Individual /Whole class

10	3. Analyze and interpret data to find the patterns of atoms interaction in a molecule. ● Have students collect data using the simulation of atoms interaction to form a molecule, and record their data in Lesson 6 activity sheet. ● Have students conduct the simulation ● Have students calculate the changes of breaking a bond, and forming a bond using the data they collected from the simulation, and fill the table in Lesson 6 activity sheet. ● Have students find the similarities and differences of bond breaking and forming from the table in the activity sheet. ● Have students interpret the data to claim that a stable molecule has less energy than the same set of separated atoms.	Small group
20	4. Construct an explanation to make a claim about how much energy should be added to the fuel to start burning. ● Introduce the idea of bond energy to students. ● Have the students construct explanations using evidence from simulations to make a claim about how much energy should be added to the fuel to start burning. ● Students share their explanations, compare and give feedback on each other's explanations. ● Students use the feedback from their discussion to make revisions and share their group explanation with the class.	Small group
5	5. Wrap up-Summarize the lesson using the Activity Summary Board ● Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question.	Whole class

Learning Sequence

Lesson Component 1: Review the Driving Question Board and Activity Summary Board

1. Review the DQB and ASB, revisit students' models of different types of chemical bonds and the simulation focusing on forming a chemical bond between different types of atoms. Connect Lesson 4 and Lesson 5 to this lesson, have students think about: How can energy be supplied to the system to break a chemical bond between the atoms? How much energy do we need to transfer to the system to break a chemical bond? How much energy is released when different chemical bonds are broken?
2. Have students turn and talk to discuss the questions above, allow students to share their responses.
3. Explain that in today's lesson, they will explore simulations to investigate the bond breaking and forming in a molecule formed by atoms with similar and different electronegativities; construct an explanation to write a claim about how much energy should be added to the molecules of the fuel in order to break the chemical bonds in the molecules and start the burning process.

Lesson Component 2: Bond breaking and forming.

1. Introduce the online simulations of pull a polar/nonpolar molecule. **Note: do not show the simulation of pulling two polar/nonpolar molecules to students.**
2. Have students use the simulation, and pull two atoms apart slowly as far as they can. Have students observe the changes of the length of an "energy star", and record the changes of potential energy when they pull two atoms apart from a molecule, and also record the changes in potential energy when the two atoms combine together to form a molecule.
3. Ask students to use the data from simulation to explain how the energy of the system changes when breaking or forming a chemical bond? Have students turn and talk to discuss the question, allow students to share their responses. Students may say that energy is always required to break a bond. Energy is released when a bond is made.

Lesson Component 3: Analyze and interpret data to find the patterns.

1. Have students collect data using the simulation of atoms interaction to form a molecule, and record their data in Lesson 6 activity sheet.
2. Have students conduct the simulation as follows:
    a. Put the two atoms at a distance of overall interaction balanced (molecule stage), record the potential energy of the stage;
    b. Pull the two atoms apart far away (overall interaction attractive stage), record the potential energy of the stage;
    c. Pull the two atoms close to each other until the overall interaction balanced (molecule stage), record the potential energy of the stage.
3. Have students calculate the changes of breaking a bond, and forming a bond using the data they collected from the simulation, and fill the table in Lesson 6 activity sheet.
4. Have students find the similarities and differences of bond breaking and forming from the table in the activity sheet. These questions should be included:
    a. How does the energy of the system changes when two atoms are far apart vs when they are close enough to form a molecule? Use the data from the table above to answer the question.
    b. For each type of fuel shown in the table, how much energy should be added to the system to break the bond between the atoms forming the molecule of the fuel ?
    c. Predict how much energy will be released when the same atoms come together to form the bond?
    d. What is the relationship between energy needed to break a bond and energy released when the same bond forms for the molecules forming different types of fuels listed in the table above? Please use the data as evidence to answer the question.
    e. Using the table above, what do you notice about how the amount of energy needed to break chemical bonds in different molecules relate to the amount of energy released when that same molecule forms?
5. Have students interpret the data to claim that a stable molecule has less energy than the same set of separated atoms. At least the difference of the amount of energy should be

added to break a chemical bond, and vice-versa, to form the same chemical bonds, the same amount of energy will be released.

Lesson Component 4: Construct an explanation to make a claim about how much energy should be added to the fuel to start burning.

1. Introduce the idea of bond energy to students: Bond energy (E) is the amount of energy required to break apart a bundle of molecules into its component atoms. It is a measure of the strength of a chemical bond. Energy is always required to break a bond and energy is released when a bond is formed.
2. Have the students construct explanations using evidence from simulations to make a claim about how much energy should be added to the fuel to start burning, such as light the paper to get start combustion. Students work individually or in pairs to complete their explanation in Lesson 6 activity sheet.
3. Students will share their explanations in a small group, and will compare and give feedback on each other's explanations. Students should focus on the following questions: did they provide a clear explanation to answer the question? What evidence did they give for their differences? Did they address the idea of bond energy properly as well as evidence from the data to explain the question? Do you agree?
4. Have students use the feedback from their discussion to make revisions and share their group explanation with the class.

Lesson Component 5: Wrap up-Summarize the lesson using the ASB

1. Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question. Refer to the Activity Summary Board: Which questions were addressed in the lesson? What did we do in the lesson? What did we learn?

Lesson 7 Why do different chemical bonds release different amounts of energy during combustion?

Lesson-level Driving Question
Why do different chemical bonds release different amounts of energy during combustion?

Lesson summary
In this lesson, students will explore simulations to investigate the atomic interaction between Noble gases to figure out why noble elements are not as reactive as other elements. Using evidence from previous lessons and the Periodic Table, students will model the structure of chemical bonds and learn to represent chemical formulas. Finally, students will use bond energy data to figure out the relationship between the types of bonds (single, double, triple), to answer the lesson driving question "why do different chemical bonds release different amounts of energy during combustion?".

Lesson-level learning goal
Students develop and use models to explain why different amounts of energy is released during the burning of different fuels.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
PS1.A: Structure and Properties of Matter ● Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. ● The periodic table orders elements horizontally by the number of protons in the atom's nucleus and	**Pattern** ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	**Develop and revise Model** ● 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. **Analyzing and Interpreting Data** ● Analyze data in order to make valid and

places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.		reliable scientific claims.
Students figure out that the noble gases are stable and do not form bonds with other elements or each other. The stability is resulting from a complete outer electron shell: all noble gases have eight outermost electrons. Losing or gaining electrons does not lead to a decrease in energy of the system or increase in stability. **Students figure out that** bond energy is different for different types of bonds as well as the distance between the chemical bonds.	**Look for students** *using evidence from online simulation, bond energy data to develop and revise the structure of chemical bonds. Ss use their models to explain "*Why do different chemical bonds release different amounts of energy during combustion?*"*	

Evidence statement

- Students develop and revise Lewis structure as a model to represent chemical bonds:
    - Model components: the number and types of atoms interacting to form a molecule. Lines represent a shared pair of electrons between atoms (a chemical bond).
    - Relationship between model components: the number of lines for connecting the interacting atoms, such as single line for sharing a pair of electrons, double lines for sharing two pairs of electrons, and triple lines for sharing three pairs of electrons.
    - Connections to phenomenon (phenomenon: explaining why different bonds release different amount of energy): the atoms interact as a type of chemical bonds are more likely to lose/gain or share so that the outermost electrons of the atoms are more likely to be found eight electrons (or two electrons) as the outermost shell of noble gases. Atoms interact by losing or gaining electrons in a way that allows them to complete the octet at the outermost shell. Having 8

electrons in the outermost shell, like in noble gases, lowers energy of the system making it more stable. Therefore, chemical bonds form when atoms achieve noble gas configuration which leads to decrease in energy and increase in stability. Different types of bonds represent atoms share amounts of electrons, which make the attractions between atoms vary, the more sharing pairs of electrons, the larger the attractions so that the distance between atoms decreased. That's why more energy would be taken to break a double or a triple bond as compared to a single bond.

Connection to other lessons in unit

In Lesson 6, students have already figured out bond energy (E) is the amount of energy required to break apart the atoms in a molecule. In this lesson, they will use the evidence from the simulation and video demonstration of noble gases, and also the real data of bond energy to figure out why bond energy vary between different types of chemical bonds during the combustion of fuel.

Materials and Preparation

Lesson 7 Activity Sheet

Safety guidelines

Basic laboratory safety guidelines.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Review the Driving Question Board and Activity Summary Board ● Review the DQB and ASB, revisit students' explanation using bond energy to explain how much energy should be added to start the fuel burning in Lesson 6. ● Have students turn and talk to discuss the questions above, allow students to share their responses. ● Explain that in today's lesson, they will explore simulations to investigate the atomic interaction between Noble gases, to figure out why noble elements are not as reactive as other elements.	Whole class
20	2. Online simulation: atomic interaction of Noble gas ● Introduce the uses of Noble gases (e.g. Helium, Neon, Argon, Kripton, Xenon and Radon) to students. ● Video demo: burning Argon gas in the bulb. ● Have students do the simulation of noble gases.	Individual/ Whole class
20	3. Represent structure of chemical bonds	Small group

	• Have students revisit the model of two hydrogen atoms, and the model of hydrogen and oxygen atoms. • Introduce **octet rule** to students as a tendency of atoms to lose or gain electrons in a way that leaves them with eight electrons in the *valence shell*. Having eight electrons in the valence shell causes significant decrease in energy and increase in stability of the system. • Have students think about oxygen and oxygen bond in O_2 molecule, and ask students what the difference is between hydrogen and hydrogen bond and oxygen and oxygen bond, and why. • Have students use Lewis structural diagram to represent the chemical bonds of some simple substance in Part 1 of Lesson 7 activity Sheet.	
20	4. Analyze and interpret data in bond energy table • Have students visit the table of bond energy and bond lengths in Part 2 of Lesson 7 activity sheet and think about the lesson driving question. • Have students turn and talk to discuss the lesson driving questions above, allow students to share their responses.	Small group
5	5. Wrap up-Summarize the lesson using the Activity Summary Board • Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question.	Whole class

Learning Sequence

Lesson Component 1: Review the Driving Question Board and Activity Summary Board

1. Review the DQB and ASB, revisit students' explanations of how much energy should be added to start the fuel burning in Lesson 6. In this lesson, have students think about: Why does bond energy vary between different types of chemical bonds during the combustion of fuel?
2. Have students turn and talk to discuss the questions above, allow students to share their responses.
3. Explain that in today's lesson, they will explore simulations to investigate the atomic interaction of Noble gases to figure out why noble gases are not as reactive as other elements.

Lesson Component 2: Video demo of burning argon gas and online simulation of atomic interaction of Noble gas

1. Introduce the uses of Noble gases (e.g. Helium, Neon, Argon, Kripton, Xenon and Radon) to students. Helium is used in balloons and "airships". Neon emits light when high voltage electricity is passed through it. Argon can be used in filament bulbs because the metal filament will not burn in Argon and it reduces evaporation of the metal filament.

2. Video demo: burning Argon gas in the bulb. Have students watch the video , and record what they saw in the Lesson 7 activity sheet. After that, have students think about why noble gas, like Argon, can't be burned like Hydrogen gas. Have students discuss in small groups and share their ideas with the group and with the whole class. Students might refer back to the Periodic Table to see the atomic structure of argon and hydrogen, and also refer back to the atomic structure of halogen and the reactivity of halogens.
3. Have students do the simulation of noble gases (Note: force should be turned on in the simulation), and discuss how energy changes are related to changes in forces, and use those ideas to explain why chemical bonds form. Have students investigate how oxygen atoms and noble gases interact with each other, and how the noble gases interact with each other. Have students look at the diagram (potential energy curve) from simulation, and use the diagram to explain why noble gases do not form bonds with other elements, and why noble gases are not as reactive as other gases (like hydrogen gas, halogen gas). Students' explanation may mention that the attractive forces between electrons and nucleus in noble gases are so strong that it's hard for the noble element to lose/gain or share electrons with other elements when they interact. According to the Periodic table, students will know that the noble elements make up a group (Group 0) of chemical elements with similar properties, there are eight valence electrons (except He) in the outermost of noble atoms, which make noble gases more stable than other gases.

Lesson Component 3: Represent structure of chemical bonds

1. First, revising concord simulation for when H2 forms a chemical bond. Have students review it again and remember that a chemical bond is formed by sharing electron density.
2. Then, do a whole group discussion about how a chemical bond in H2 can be represented on paper in 2D. In that discussion ask students to recall how many valence electrons each H atom has, remind them that only valence electrons are involved in forming a chemical bond, and show them on the board that a way to represent the sharing of electron density between 1 pair of electrons in 2D is by simply drawing a line between the two H atoms. Contrast the 2D drawing on the board with the snapshot from the concord simulation so they associate electron density sharing with the line between the 2 H atoms.
3. Ask students how many electrons in the outermost shell each H atom has when they form a bond vs when they are separate. Help them understand that since both atoms are sharing the electrons, each atom now has 2 electrons in the outermost shell. Ask them if any other element in the periodic table has 2 electrons in the outermost shell. They should figure out it is Helium.
4. Ask them to go back to the Phet simulation and recall what makes helium special (it is not reactive). Ask them why helium is not reactive (it is stable, it is in a low energy state because of the complete outermost electron shell). Since each H atom in H2 molecule now also has a complete outermost electron shell, the H2 molecule is in its low energy state, and therefore stable. Therefore, forming a chemical bond decreases the energy of the system for the two H atoms because they now have a complete outermost shell. This decrease in energy is what causes a molecule to be stable, just like a noble gas.
5. Then, once they understand H2, do a similar example with H-O and discuss that oxygen now completes the outermost electron shell by gaining electrons from H and having a total 8 electrons. Give them a couple more examples and discuss.

Lesson Component 4: use Octet rule to draw Lewis structure model

1. Introduce **octet rule** to students that refers to the tendency of atoms to prefer to have eight electrons in the *valence shell*. When atoms have fewer than eight electrons, they tend to react and form more stable compounds. Introduce students how to draw Lewis structure models to represent chemical bonds. For example, hydrogen and hydrogen bonds can be represented as H-H, and hydrogen and oxygen bonds can be represented as H-O.
    a. Find the total number of valence electrons.
    b. Put the least electronegative atom in the center.
    c. Put two electrons between atoms to form a chemical bond.
    d. Complete octets (means 8) on the outside atoms.
2. Have students think about oxygen and oxygen bonds in O_2 molecules, and ask students what the differences between hydrogen and hydrogen bond and oxygen and oxygen bond, and why? Have students turn and talk to discuss, and allow students to share their responses. Students may draw the structure of oxygen and oxygen bond as O=O, and explain that two oxygen atoms share two pairs of electrons so that each oxygen is more likely to be found eight electrons in the outermost shell like a Neon atom.
    a. Have students know that a Lewis structure shows you exactly how many electrons are involved in each bond in a compound.
    b. Some Lewis structures show bonding pairs as lines between atoms.
    c. A structural diagram shows single bonds as single lines and multiple bonds as multiple lines. It does not show non-bonding pairs. It is less cluttered than a Lewis structure. It clearly shows whether the bonds involved are single, double, or triple bonds.
3. Have students use Lewis structural diagram to represent the chemical bonds of some simple substance in Part 1 of Lesson 7 activity Sheet.

Lesson Component 5: Analyze and interpret data in bond energy table

1. Have students visit the table of bond energy and bond lengths in Part 2 of Lesson 7 activity sheet and think about the lesson driving question: why does bond energy vary between different types of chemical bonds during the combustion of fuel? To explain the lesson driving question, some sub-questions are listed as follows:
    a. Why do different bonds have different lengths using the idea of forces and electric attraction between components of atoms?
    b. What is the relationship between bond energy and the length of bond?
    c. Why double bond (or triple bond) energy is larger than single bond when two atoms interact, such as C-O vs C=O? Which one is more stable, and why?
2. Have students turn and talk to discuss the lesson driving questions above, allow students to share their responses. Remind students that these should ideally be supplemented with snapshots from relevant simulations that they already used in the activity.

Lesson Component 6: Wrap up-Summarize the lesson using the Activity Summary Board

1. Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question. Refer to the Activity Summary Board: Which questions were addressed in the lesson? What did we do in the lesson? What did we learn?

Lesson 8 What happens to the fuel and surroundings at molecular level when the fuel burns?

Lesson-level Driving Question
What happens to the fuel and surroundings at molecular level when it burns?

Lesson summary
Students will start developing their own models to describe the changes in the fuel and surroundings at molecule level, and use the model to explain why we may feel warm when the fuel is burned using the idea of breaking and forming chemical bonds from Lesson 4-6.

Lesson-level learning goal
Students develop and revise a model to describe the changes of energy and matter both in the system and surroundings at molecular level when the fuel is burned.

Lesson level 3-dimensional components:

<table>
<tr><th>Disciplinary core ideas</th><th>Crosscutting concepts</th><th>Science and engineering practices</th></tr>
<tr><td>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 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.</td><td>Energy and Matter
● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.</td><td>Develop and revise Model
● 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</td></tr>
<tr><td>Students figure out that the net change of energy within the system of the burning candle is the result of bonds that were broken and formed during the reaction. The combustion of candle releases energy because the relative potential energies of</td><td colspan="2">Look for students using evidence from previous lessons and the potential energy diagram to develop and revise their particle-models of candle burning reaction.Ss use their models to explain “ what happened to the fuel and surroundings at molecular level when it burned”.</td></tr>
</table>

the reactants and products decreased, and energy was transferred to the surroundings because products have more kinetic energy.	

Evidence statement
Students' model should include the following aspects:

- Components:
    - The chemical reaction, the system, and the surroundings in combustion reaction;
    - The reactants (candle and oxygen) and the bonds (C-H and O-O) that are broken during the candle burning; The products (carbon dioxide and water) and the bonds (C-O; H-O) that are formed after the candle burned;
    - The energy transfer between the systems and components of the system and surroundings; relative potential energies of the reactants and the products.
- Relationships:
    - The net change of energy within the system is the result of bonds that are broken and formed during the candle burning process;
    - The net amount of energy released depends on the relative potential energies of the reactants and products.
- Connections: Students use the model they developed to illustrate:
    - The energy change within the system is accounted for by the change in the bond energies of the reactants and products. Breaking bonds requires an input of energy from the system or surroundings, and forming bonds releases energy to the system and the surroundings.
    - The net energy change of combustion reaction is the difference in energy between the bond energies of the reactants and the products. The relative total potential energies of the reactants and products can be accounted for by the changes in bond energy.

Connection to other lessons in unit
In this lesson, students develop models to describe the changes in the fuel and surroundings at molecule level, and use the model to explain why we may feel warm when the fuel is burned using the idea of chemical bonds from Lesson 4-6.

Materials and Preparation

Lesson 8 activity sheet

Safety guidelines

Basic laboratory safety guidelines.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Review the Driving Question Board and Activity Summary Board ● Review the DQB and ASB, discuss student ideas about the observations made in Lesson 3 of the changes of the fuel (candle) and surroundings and the unit driving question. ● Have students turn and talk to discuss the question. ● Explain that in today's lesson, they will start developing their own models to describe the changes of the fuel and the surroundings at molecule level, and then use the model to explain why we may feel warm when the fuel is burned. ● Students come back and revise their models several times based on new ideas they learned.	Whole class
20	2. Introduce potential energy diagram of a reaction system as the reaction process ● Have students think about what the total bond energy changed before and after fuel burned. ● Introduce potential energy diagrams to students. ● Have students use the idea of bond energy and bond breaking and forming to describe how the potential energy changed when a candle reacted with oxygen. ● Have students think about how to include the component of energy transfer in their molecular level models to describe how energy of the system changes during candle burning.	Whole class
15	3. Discuss the components of model related to the driving question ● Have students develop and revise a model to describe the changes in the candle and the surroundings when it is burned based on new ideas they explored. ● Discuss with the students what are the components of the system they should include in their initial model and how they think they should relate to each other. ● Ask students to name the components they wish to add to their model.	Whole class/ Small group
30	4. Develop and revise the initial models to describe what happened to the fuel and surroundings at molecular level when the fuel burns? ● Ask students to construct their models using paper and pencil in Lesson 8 activity sheet. ● Let students develop their model. ● Have students share their models with another group. ● After receiving the feedback, provide students with several more minutes to revise their models.	Small group
5	5. Wrap up-Summarize the lesson using the Activity Summary Board	Whole class

	• Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question. • Refer to the Activity Summary Board.	

Learning Sequence

Lesson Component 1: Review the Driving Question Board and Activity Summary Board

1. Review the DQB and ASB, discuss student ideas about the observations made in Lesson 3 of the changes of the fuel (candle) and surroundings and the unit driving question. Have students think about how they can describe the changes in the fuel (candle) and energy at the micro-level when it is burning. Use the ideas of chemical bonds and energy from Lesson 4-6.
2. Have students turn and talk to discuss the question. Allow students to share their ideas on how to draw a model to describe changes in the fuel (candle) and the surroundings at micro-level.
3. Explain that in today's lesson, they will start developing their own models to describe the changes of the fuel and the surroundings at molecule level, and then use the model to explain why we may feel warm when the fuel is burned.
4. They will come back and revise their models several times based on new ideas they learned. Explain that students and scientists can use different model types to make sense of phenomena or solve problems.

Lesson Component 2: Introduce potential energy diagram

1. Remind students about bond energy and that different amounts of energy were added to break or form different bonds in Lesson 6. Have students think about what the total bond energy changed before and after fuel burned.
2. Introduce potential energy diagrams to students. A potential energy diagram shows the total potential energy of a reacting system as the reaction proceeds. In Lesson 8 activity sheet, have students examine carefully the potential energy diagram of the combustion reaction of a candle. Ask students several questions to deepen their understanding of the potential energy diagram. [Note: The **energy** changes that occur during a chemical reaction can be shown in a **diagram** called a **potential energy diagram**, or sometimes called a reaction progress curve. A **potential energy diagram** shows the change in **potential energy** of a system as reactants are converted into products]. These questions can be asked as follows:
    a. How much energy does the system (reactants of candle and oxygen) has before the candle burns?
    b. How much energy should be added to start the candle burned?
    c. How much energy is transferred when carbon dioxide and water are produced after the candle burns?
    d. How much energy do the products (carbon dioxide and water) have after the candle burned?
    e. What is the net amount of energy transferred to the surroundings after the candle burned?
    f. Why once the wick is lit you no longer have to add energy?

3. Have students use the idea of bond energy and bond breaking and forming to describe how the potential energy changed when a candle reacted with oxygen. Students are expected to know that the net change in energy within the system is the result of bonds that were broken and formed during the reaction. The combustion of candles releases energy to the surroundings because the potential energy of the reactants is greater than the potential energy of the products, and therefore the net energy change is positive.
4. Have students think about how to include the component of energy transfer in their molecular level models to describe how energy of the system changes during candle burning.

Lesson Component 3: Discuss the components related to the driving question

1. Remind students of the initial models they developed in Lesson 1. Have students develop and revise a model to describe the changes in the candle and the surroundings when it is burned based on new ideas they explored. Have students think about how they can show the changes in reactants (candle and oxygen) and products (carbon dioxide and water) at the molecule level; as well as energy changes including energy transfer into the system (burning candle) and the surroundings, and between the reactants and the products within the system of the combustion reaction.
2. Remind students how to create a model: choosing components, defining the relationships between components, defining connections to phenomena they are trying to explain.
3. Discuss with the students what are the components of the system they should include in their initial model and how they think they should relate to each other. Remind them what about the components they have explored so far. List students' suggestions on the board, encourage students to include every component they think is relevant in their models, but to remember that the components have to be relevant to the phenomenon they are trying to explain and the driving question.
4. Ask students to name the components they wish to add to their model. For instance, use the component "candle", "flame", "bonds in reactants and products", "energy transfer", "temperature of the surroundings" and "bond breaking and forming".

Lesson Component 4: Develop and revise the initial models

1. Ask students to construct their models using paper and pencil in Lesson 8 activity sheet. Make sure they write their explanation for each relationship. Students should work in small groups on their models.
2. Let students develop their model. Ask students to include the question/goal of their models. Ask students to create their models and include the components they explored in the investigation. They should start by describing the phenomenon they want to explain using their models. After that, they should represent each component, label it as a component, connect the components with arrows or signs (show relationships), and define the relationship between all components (between each arrow or sign).
3. While constructing their models, have students reflect on the following questions:
    a. What are the important components of the system?
    b. Which, if any, of the above component(s) of the system should be left out to keep your model simple and easy to understand?
    c. How do the components of the system interact? What is the role of each component in explaining the phenomenon?

4. Have students share their models with another group. Direct them to give constructive feedback to each other, listen to each other and to be tolerant and polite.
5. After receiving the feedback, provide students with several more minutes to revise their models. While sharing their models with their partner, have students focus on the following questions:
    a. Compare your model to the other model. What is similar, what is different?
    b. What are the criteria you would use to evaluate if a model is good or not?
    c. Do you have any suggestions about how to make your model better?
6. Point for discussion:
    a. What is good about the presented models and what could be improved?
    b. What questions do students have for their classmates regarding why they set up the models this way?

<u>Lesson Component 5: Wrap up-Summarize the lesson using the Activity Summary Board</u>

1. Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question.
2. Refer to the Activity Summary Board: Which questions were addressed in the lesson? What did we do in the lesson? What did we learn? Transfer the questions that were addressed in the lesson from the DQB to the ASB and complete the rest of the row (what did we do? What did we learn?).

Lesson 9 Do all chemical reactions release energy?

Lesson-level Driving Question
Do all chemical reactions release energy?

Lesson summary
Students investigate the chemical reaction of mixing $Ba(OH)_2$ reacting with NH_4Cl, draw the potential energy diagram of this reaction, and then construct an explanation using the evidence from the reaction to support their claims that not all chemical reactions release energy as fuel burns, but some reactions can also absorb energy from surroundings so that we may feel colder.

Lesson-level learning goal
Students construct explanations using evidence to support their claims that not all chemical reactions release energy, but some reactions can also absorb energy from surroundings so that we may feel colder.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
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 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.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.	• Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
Students figure out that some chemical reactions, like the reaction of $Ba(OH)_2$ and NH4Cl, absorb energy from the surroundings	**Look for students** constructing explanations using evidence to support their claims that not all chemical reactions release energy, but some reactions (e.g., the chemical reaction of $Ba(OH)_2$ reacting NH_4Cl) can also absorb energy from surroundings so that we may feel colder.	

rather than releasing energy.	

Evidence statement
Students' explanation should include the following aspects:
- Claim: Not all chemical reactions release energy, but some reactions can also absorb energy from surroundings so that we may feel colder.
- Evidence(s): The chemical reaction of $Ba(OH)_2$ and NH_4Cl absorbs energy from the surroundings. They know this because the water froze and they felt that the beaker got cold.
- Reasoning:
    - The net change of energy within the system is the result of bonds that are broken and formed during the chemical reaction of mixing $Ba(OH)_2$ reacting with NH_4Cl;
    - The absorption of energy depends on the relative potential energies of the reactants ($Ba(OH)_2$ and NH_4Cl) and the products($BaCl_2$, NH_3 and H_2O). Since the water froze, this indicates that energy was transferred from the surroundings into the system, indicating that potential energy of reactants is lower than that of products formed in this reaction.

Connection to other lessons in unit
In the previous lessons, students investigated the chemical reactions that release energy, such as candle burning. In this lesson, students will think about whether all chemical reactions release energy; What happens if a chemical reaction absorbs energy from the surroundings?

Materials and Preparation

Teacher Demo:
One 250 mL Erlenmeyer Flask
Barium Hydroxide (32g pre-measured)
Ammonium Chloride (11g pre-measured)
One DI water Rinse Bottle
One small Block of Wood
One Stirring glass rod

Per student:
Gloves and Goggles
Lesson 9 Activity Sheet

Safety guidelines

Standard laboratory safety guidelines when experimenting. Protective gloves and protective glasses should be used by all students. Goggles need to be worn and long hair tied back. No loose clothing, etc. Procedures for chemical waste disposal.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	1. Review the Driving Question Board and Activity Summary Board • Review the DQB and ASB • Have students turn and talk to discuss the question, allow students to share their ideas to class. • Explain today's driving question. • Explain that they will conduct an investigation to gather evidence to support their claims whether all chemical reactions release energy as fuel burned.	Whole class
20	2. Teacher Demo: investigate the reaction of mixing $Ba(OH)_2$ and NH_4Cl • Have students observe what happens if we combine $Ba(OH)_2$ with NH_4Cl in a beaker, ask them to write their predictions in Lesson 9 activity sheet. • Have students do the investigation following the instructions. • Have students observe and record their observations in Lesson 9 activity sheet.	Whole class
10	3. Draw a potential energy diagram for how the energy of the system changed during the chemical reaction of Ba(OH)2 and NH4Cl. • Have students think about how the energy of the system changed during the chemical reaction. • Have students discuss the questions using evidence gathered from the investigation. • Have students draw the potential energy diagram in Lesson 9 activity sheet.	Small group
20	4. Construct explanations to answer the question, "do all chemical reactions release energy?" • Have students think about the differences in energy changes between combustion of candle and reaction of $Ba(OH)_2$ with NH_4Cl? • Have students discuss the differences and similarities of the two types of reactions, and direct them to use the models they constructed and the potential energy diagram as evidence to explain the differences between the two types of reactions. • Students share their explanations in a small group, and compare and give feedback for explanations. • Have students use the feedback from their discussion to make revisions and share their group explanation with the class.	Small group/ Whole class
5	5. Wrap up-Summarize the lesson using the Activity Summary Board • Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question. • Refer to the Activity Summary Board.	Whole class

Learning Sequence

Lesson Component 1: Review the DQB and ASB

1. Review the DQB and ASB, and have students think about whether all chemical reactions release energy? What happens if a chemical reaction absorbs energy from surroundings?
2. Have students turn and talk to discuss the question, allow students to share their ideas to class.
3. Explain today's driving question: Do all chemical reactions release energy? What happens if a chemical reaction absorbs energy from surroundings? How can we use the idea from previous lessons to explain absorption of energy from the surroundings during a chemical reaction?
4. Explain that in the following activity, they will conduct an investigation to gather evidence to support their claims whether all chemical reactions release energy as fuel is burned.

Lesson Component 2: Teacher Demo: investigate the reaction of $Ba(OH)_2$ with NH_4Cl

1. In small groups, have students observe what happens if we combine $Ba(OH)_2$ with NH_4Cl in a beaker, ask them to write their predictions in the Lesson 9 activity sheet.
2. Have students do the investigation following the instructions: place 32gms $Ba(OH)_2$ in a 250ml Erlenmeyer flask, record the temperature of the substance using a thermometer and then add 11gm NH_4Cl, have students touch the beaker, and measure the temperature of the beaker inside before mixed, and shake gently to mix. Wet a small wooden block with a small amount of water and set the flask on it. Have students touch the beaker, and measure the temperature of the beaker again, and record the temperature.
3. In about 30 seconds, have students observe very carefully, and record their observations in Lesson 9 activity sheet. Students' observations may include a pungent smell of a gas that was formed, and a kind of liquid was also formed, and the flask froze to the wood. The temperature of the beaker decreased after two substances mixed.

Lesson Component 3: Draw potential energy diagram

1. Have students think about how the energy of the system changed during the chemical reaction? Did the reaction release or absorb energy when we mixed the two substances? How do you know? What does it mean that the temperature decreased?
2. Have students discuss the questions using evidence gathered from the investigation. Ask them to draw a potential energy diagram to describe the total potential energy change of the system of mixing $Ba(OH)_2$ and NH_4Cl as the reaction proceeds.
3. Have students draw the potential energy diagram in Lesson 9 activity sheet, and use the potential energy diagram to support their claims whether the reaction of $Ba(OH)_2$ with NH_4Cl released energy.

Lesson Component 4: Construct explanations

1. Have students think about the differences in energy changes between combustion of candle and reaction of $Ba(OH)_2$ with NH_4Cl?
2. In groups, have students discuss the differences and similarities of the two types of reactions, and direct them to use the models they constructed and the potential energy diagram as evidence to explain the differences between the two types of reactions. Use the evidence from the combustion of candles and the reaction of Ba(OH)2 with NH4Cl,

answer the question: do all chemical reactions release energy? Students will work individually or in pairs to complete their explanations in the Lesson 9 activity sheet.

3. Students will share their explanations in a small group, and will compare and give feedback for explanations. Students should focus on the following questions: did they provide a clear explanation to answer the question? What evidence did they give for their claims? Did they address the idea of bond energy properly as well as evidence from the data to explain the question? Do you agree?
4. Have students use the feedback from their discussion to make revisions and share their group explanation with the class.

Lesson Component 5: Wrap up-Summarize the lesson using the Activity Summary Board

1. Summarize the activities from the lesson and have students reflect on what they learned and still need to figure out how to answer the driving question.
2. Refer to the Activity Summary Board: Which questions were addressed in the lesson? What did we do in the lesson? What did we learn? Transfer the questions that were addressed in the lesson from the DQB to the ASB and complete the rest of the row (what did we do? What did we learn?).

Lesson 10 Why can we burn fuel to keep ourselves warm?

Lesson-level Driving Question
Why can we burn fuel to keep ourselves warm?

Lesson summary
Students revise their models based on evidence from previous lessons. Students answer and explain the unit driving question using ideas related to the energy change within the system as accounted for by the change in the bond energies of the reactants and products; breaking bonds requires an input of energy from the system or surroundings, and forming bonds releases energy to the system and the surroundings; the energy transfer between systems and surroundings is the difference in energy between the bond energies of the reactants and the products; the overall energy of the system and surroundings is unchanged (conserved) during the reaction; the relative total potential energies of the reactants and products can be accounted for by the changes in bond energy.

Lesson-level learning goal
Students develop and use models to explain why we can burn fuel to keep ourselves warm.

Lesson level 3-dimensional components:

Disciplinary core ideas	Crosscutting concepts	Science and engineering practices
PS1.A: Structure and Properties of Matter A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. PS1.B: 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 rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. **Systems and system models** • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and	**Developing and Using Models** • Develop, revise, and/or use model based on evidence to illustrate and/or predict the relationships between systems or between components of a system

matched by changes in kinetic energy.	between systems at different scales.	
Students figure out that the reason why we can burn fuel to keep ourselves warm is that the combustion reaction can release energy to the surroundings so that we feel warm.	**Look for students** using the evidence from previous lessons about the relative potential energy of the reactants and products, the chemical bonds of reactants and products, and the energy transfer between the system and the surroundings to develop a model to explain why we can burn fuel to keep ourselves warm.	

Evidence statement
Students' model should include the following aspects:

- Components:
  - The chemical reaction, the system, and the surroundings The reactants and the bonds that are broken during the candle burning; The products and the bonds that are formed after the candle burned;
  - The energy transfer between the systems and their components or the system and surroundings; and the relative potential energies of the reactants and the products.
- Relationships:
  - The net change of energy within the system is the result of bonds that are broken and formed during the fuel burning;
  - The release or absorption of energy depends on the relative potential energies of the reactants and products decrease or increase
- Connections: Students use the developed model to illustrate:
  - The energy change within the system is accounted for by the change in the bond energies of the reactants and products. Breaking bonds requires an input of energy from the system or surroundings, and forming bonds releases energy to the system and the surroundings.
  - The energy transfer between systems and surroundings is the difference in energy between the bond energies of the reactants and the products. The relative total potential energies of the reactants and products can be accounted for by the changes in bond energy.

Connection to other lessons in unit
Students figure out the answer and explain the unit driving question using evidence found in this unit's lessons.

Materials and Preparation

Equipment and materials-
Per group/student:

- Poster
- Sticky notes
- Unit assessment task

Safety guidelines

None required.

Suggested time and sequence of the lesson

Time (min.)	Lesson Components	Setting
10	Introduction-Review the Driving Question Board and Activity Summary Board • Review the DQB and ASB, and have students think about the unit driving question: why we can burn fuel to keep ourselves warm? • Remind students of the phenomena they experienced in previous lessons, and the models they constructed based on evidence from investigations and simulations. • Explain that today they will choose one kind of fuel from their daily life (except burning candle) mentioned in Lesson 2 to develop and use a model to explain the fuel burns.	Whole class
20	Develop and use a model to explain the unit driving question • Have students work in small groups to choose one kind of fuels (e.g. solid, liquid, or gaseous), and ask them to draw and use a model to explain the phenomena. • Ask students to include the question/goal of their models. • Have students evaluate their own paper pencil models.	Small group
15	Gallery walk: providing feedback to other group models • Have students place their models around the classroom. • Remind students that evaluation should be focused on the model and be relevant to explaining the target phenomenon.	Whole class
10	Revise and finalize their models • Students return to their own models and review the feedback notes they received. • Students make a final revision to their models based on the feedback they received.	Small group
15	Summarize the unit using the Driving Question Board and Activity Summary Board • Summarize the unit and have students reflect on what they learned about the driving question. • Refer to the Driving Question Board and Activity Summary Board.	Whole class

Learning Sequence

Lesson Component 1: Introduction-Review the DQB and ASB

1. Review the DQB and ASB, and have students think about the unit driving question: why we can burn fuel to keep ourselves warm?
2. Remind students of the phenomena they experienced in previous lessons, and the models they constructed based on evidence from investigations and simulations.
3. Explain that in today's activity they will choose one kind of fuel from their daily life (except burning candle) mentioned in Lesson 2 to develop and use a model to explain the fuel burns. Ask them to develop and use a model based on their experiences of modeling in Lesson 7 of burning candle.

Lesson Component 2: Develop and use a model to explain the phenomena

1. Provide three kinds of scenarios for burning fuel in daily life. Have students work in small groups to choose one kind of fuels (e.g. solid, liquid, or gaseous), and ask them to draw and use a model to explain the phenomena.
    a. Scenario 1: Why do we feel warm when we burn natural gas to cook food at home?
    b. Scenario 2: Why do we feel warm when burning wood in outdoor activity?
    c. Scenario 3: Why do we feel warm when we use alcohol burners in chemistry lab?
2. Starting to develop their models. Ask students to include the question/goal of their models. Ask students to create their models to represent the components they explored in the investigation. They should start by stating the driving question they want to answer using their models. After that, they should represent each component, label it as a component, connect the components with arrows or signs (show relationships), and define the relationship of each arrow or sign.
3. While constructing their models, have students reflect on the following questions:
    a. What are the important components of the system?
    b. Which if any of the above component(s) of the system should be left out to keep your model simple and easy to understand?
    c. How do the components of the system behave? What are each of the components of the system doing during the process?
4. Have students to evaluate their own paper pencil models using the following guiding questions:
    a. Does your model provide a full and appropriate explanation to the driving question of the unit?
    b. Does your model include all relevant variables and appropriate relationships to be included in the system?
    c. Do you have evidence and reasoning for all the relationships in our model?
    d. Can your model be used to predict the changes in the system? How? What would be the outcome of these changes?
5. If the answer to any of these questions is 'no', ask students to consider what they need to do to revise their models and have them do so.

Lesson Component 3: Gallery walk: providing feedback to other group models

1. Have students place their models around the classroom. Provide each student with several sticky notes and ask students to walk around the tables and evaluate other students' models. If they want to add a comment or suggestion, they can write it on a sticky note and place it next to the students' models.

2. Remind students that evaluation should be focused on the model and be relevant to explaining the target phenomenon. It should NOT be offensive or judgmental, but provide possible suggestions to make the model better or ask questions to clarify issues related to the model.

<u>Lesson Component 4: Revise and finalize their models</u>

1. In the final part of the lesson, students return to their own models and review the feedback notes they received.
2. They discuss each comment/ suggestion, and can make a final revision to their models based on the feedback they received.

<u>Lesson Component 5: Summarize the unit using the DQB and ASB</u>

1. Summarize the unit and have students reflect on what they learned about the driving question.
2. Refer to the Driving Question Board and Activity Summary Board: Which questions still remain? What other questions can we ask about the driving question and anchoring phenomena?