

BIOLOGY

Ecosystems
Matter & Energy

**What causes fires
in ecosystems to
burn and how
should we
manage them?**



HIGH SCHOOL SCIENCE



TEACHER EDITION



What causes fires in ecosystems to burn and how should we manage them?

Ecosystems Matter & Energy: Fires

OpenSciEd Unit B.2





Version 1.0 - Copyright © 2023 OpenSciEd

Licensed under the Creative Commons NonCommercial Attribution 4.0 International License (CC BY-NC 4.0). The OpenSciEd name and logo are not subject to the Creative Commons license and may not be used without the prior and express written consent of OpenSciEd. The OpenSciEd high school classroom curriculum materials are licensed under the CC-BY-NC 4.0 license.

Although the CC-BY-NC License is limited to non-commercial uses, commercial uses of our classroom curriculum materials are still encouraged and will now be available pursuant to our License for Commercial use of Curriculum Materials, which supplements the CC-BY-NC License. Commercial uses of a certain scale may require the payment of fees to OpenSciEd to support the development and maintenance of the OpenSciEd assets.

You may copy, distribute and modify the OpenSciEd curriculum materials for Non-Commercial purposes pursuant to the terms and conditions of the CC-BY-NC license, which requires, in part, that you provide attribution to OpenSciEd, and, for online uses, provide a prominent hypertext link back to OpenSciEd's website located at www.opensciEd.org. "Non-Commercial" shall have the meaning given to such term in the CC-BY-NC License; subject to compliance with its terms, such license would permit use for academic purposes of the Curriculum Materials obtained through publicly available means, so long as such use is not commercial in nature. The above is a short summary of OpenSciEd's interpretation of the CC-BY-NC License, and is not a substitute for the full text of the CC-BY-NC.

This curriculum includes images that are public domain, openly licensed, or used by explicit agreement with their owners. See the attribution information with each image for ownership details and any restrictions on its use. Unless otherwise noted in the image attribution information, all images are licensed for distribution under the terms of the Creative Commons Attribution License (CC BY 4.0) by OpenSciEd or by their respective owners, or they are in the public domain.

The development of this material was supported by the Bill & Melinda Gates Foundation, Carnegie Corporation of New York, Walton Family Foundation, and William and Flora Hewlett Foundation.

To download the handouts, slides, and other unit resources, visit OpenSciEd.org and complete the free registration.



This work is licensed under a Creative Commons NonCommercial Attribution 4.0 International License along with OpenSciEd's License for Commercial Use of Curriculum Materials v1.0.

Unit Development Team

Jamie Deutch Noll, Unit Lead, BSCS Science Learning
Melissa Campanella, Writer, University of Colorado Boulder
Kate Henson, Writer, University of Colorado Boulder
Sara Krauskopf, Writer, University of Colorado Boulder
DeAnna Lee-Rivers, Writer, University of Colorado Boulder
Christina Torres, Writer, Columbia University
Sarah Donovan, PsyD, Consultant Expert, SafeSide Prevention

Production Team

inquiryHub, University of Colorado Boulder
Madison Hammer, Production Manager
Amanda Howard, Copy Editor
Erin Howe, Project Manager
Celeste Moreno, Media Producer

OpenSciEd

James Ryan, Executive Director
Sarah Delaney, Senior Director
Matt Krehbiel, Senior Director

High School Science Developers Consortium

inquiryHub, University of Colorado Boulder
William Penuel, Director
Tamara Sumner, Co-Director
Kate Henson, Co-Director, Course Coordination Lead, Biology Course Lead
Dawn Novak, Professional Learning Lead
Kristin Rademaker, Professional Learning Specialist
Ann Rivet, Advisor on ESS Integration

BSCS Science Learning

Daniel C. Edelson, Director
Zoë Buck Bracey, Associate Director, Physics Course Lead
Kevin Cherbow, Professional Learning Specialist

Northwestern University

Brian Reiser, Director
Michael Novak, Associate Director
Nicole Vick, Chemistry Course Lead
Samantha Pinter, Professional Learning Specialist

Charles A. Dana Center, The University of Texas at Austin

Shelly LeDoux, Director
Carol Pazera, Senior Research Analyst
Renee Andrews, Senior Administrative Associate
Molly Ewing, Professional Learning Specialist
Courtney Howard, Project Manager, Operations

Denver Public Schools

Douglas Watkins, District Partner Director

State Steering Committee

California

Jill Grace
Susheela Valdez

Iowa

Christopher Like
Jason Martin-Hiner
Tami Plein

Louisiana

Tana Luther
Breigh Rhodes
John Underwood

Massachusetts

Casandra Gonzalez
Erin Hashimoto-Martell
Nicole Scola

Michigan

Mary Starr
Michael Tanoff

New Jersey

Michael Heinz
Ivory Williams

New Mexico

Shafiq Chaudhary
Yanira Vázquez

Oklahoma

Heather Johnston

Rhode Island

Erin Escher
Carolyn Higgins
Phyllis Lynch

Washington

Johanna Brown
Ellen Ebert

Field Test Teachers

California

Dayna Drewniak
Candace Farah
Autumn Ferrugia
Chad Franks
Kevin Glatt
Cari Glenning
Kevin Haman
Opal Hargett
Brian Hofsteen
Laura Hollister
Kyle Hutchins
Kay Isbell
Shawna Jaggi
Carl Maas
Sarah Stottlemeyer

Iowa

Melissa Greene
Nathaniel Hemming
Kalynn Martinez
Michelle Seddon
Alicia Schiller Haynes

Louisiana

Erin Becnel
Chiara Crawford
Roxanna DarDar
Brittany Douget
Haley Landry
Cortney Logan
Jordan Ortega
Ciara Riggs (Howes)
Aaron Snatic
Victoria Vercher
Caitlin Lapeyrouse*
Annie Jo St. Pierre

Michigan

April Barnier*
Joshua Hubbard
Adam Luck
Courtney Lutz
Aaron Moran
Carl Ray
Erica Rothwell
Julie Tafelski
Megan Terry
New Mexico
Marie Booth
Shay Colburn
Tarla Hill
Inez Jacobs
Bindu Kaimal
Karen McCauley
Tanya Moya
Sharla Rusk
Misty Torres

Massachusetts

Cullen Bartel
Matt Blennau
Garrett Brune
Paul Champlin
Anna Chase
Tammy Cullins
Enrique Durand
Ross Ferguson
Tara Frare
Matthew Furtado
Jameson Gasparri
Nicole Jalbert
Anthony Keeler
Ivyrose Likis
Amanda Machado
Marissa Mota*
Katelyn Owens
Andy Rithiphong
Shelly Romero
Jaime Ruiz II
Heather Sanborn
Sal Sciascia
Gabrielle Sears
Michele Shaw
Alexander Sousa
Ann Taft
Alyssa Tausevich
Page Veazie
Johanna Waldman
Jenna Viera (Morton)
Wendy Reigel
(Bradbury)

Oklahoma

Gail Ciano
Ethan Cox
Richard Dixon
Bryan Frenette
Amanda Gargan
Madison Glennie*
Victoria Glover
Natasha Hillis
Bianca Melendez
Tara Schropp
Jennifer Shaw
Kelsey Stewart
Melinda West
Tammy Wood
Brylee Bode (Dash)

Rhode Island

Lara Haggerty
Jessica Oliva

Washington

Alicia Arnold
Jim Christian
Rama Devagupta
Sam Garson
Brandi Hageman*
Ryan Josephson
Carmen Kardokus
Nina Markham
Margaret Miller
Allison Neils-Lamoine
April Peterson
Tim Renz
Cortney Rhoades
Sarah Templin
Susan Wierenga
Ashley Williams

Pilot Teachers

Denver Public Schools

Gayon Brown
Joseph Marlen
Andres Rodriguez
James Smith

*Special thanks to teachers who participated in the co-revision process.

TABLE OF CONTENTS

Unit B.2 What causes fires in ecosystems to burn and how should we manage them?

Unit Overview	1
Unit Storyline	3
Teacher Background Knowledge	10
Home Communication	25
Lesson 1: How can fires burn under ice and release so much energy and matter?	27
Lesson 2: What is peat and why does it burn so much?	55
Lesson 3: Why is there so much peat that has not decomposed in the permafrost?	75
Lesson 4: How did so much plant energy and matter get into the peat in the zombie fire system?	103
Lesson 5: Could changes in the Earth's tilt cause more energy and matter to be stored in plants?	113
Lesson 6: How do zombie fires disrupt the flow of energy and cycle of matter in Arctic ecosystems?	131
Lesson 7: What is happening to carbon sinks in other ecosystems?	147
Lesson 8: Why should we be concerned that carbon sinks around the world are burning?	167
Lesson 9: What are the global effects of increased carbon dioxide from fires?	185
Lesson 10: How can we help manage the matter and energy in fire systems?	207
Lesson 11: What decisions can we make to help manage fire in communities we care about?	229
Lesson 12: Can we use everything we have figured out about fires to explain a new phenomenon?	247
Unit B.2 Teacher Reference Materials	253
Unit B.2 Lesson-Specific Teacher Materials	268

UNIT OVERVIEW

What causes fires in ecosystems to burn and how should we manage them?

This unit is designed to deepen student understanding of the flow of matter and energy ecosystems and the cycling of carbon on a global scale due to increased fires. Students spend the first 6 lessons investigating the story of matter and energy in the peat/permafrost system. Students observe and burn peat, then investigate how it formed in the first place. This leads them to wonder why there is so much peat frozen in the permafrost and to conduct an investigation for decomposition by cellular respiration at different temperatures. Next, students grapple with how there could be so many plants in the cold Arctic and figure out that there was more solar radiation when the plants that formed the peat lived, allowing more plants to grow and photosynthesize. Students figure out that when there is enough sunlight, plants can store sugar in larger molecules like starch. With all of the evidence students have collected, they are now ready to revise their models for explaining how the zombie fires burn under ice and release so much carbon dioxide and energy. Students wonder if there are other carbon sinks that might be burning like the peat in zombie fires, so they look at maps of recent fires to figure out which locations might be productive to investigate. Students uncover that in all of these burning carbon sinks, there are either land use changes, drought, and/or higher temperatures. Students worry about what this means on a bigger scale and what the connection is between increased carbon dioxide and temperature. Students then conduct an investigation with varying levels of carbon dioxide, analyze data, and use a quantitative model to determine that there are feedback effects from human activity that increase carbon dioxide and temperature on a global scale. This motivates students to look for successful cases of fire management that disrupt the flow of matter and energy, so that they may design a fire management solution for a community they care about.

As part of the process of investigating “What causes fires in ecosystems to burn and how should we manage them?”, students will:

- Develop, use, and revise a model of the matter and energy flow in zombie fire systems so that they can apply this model to other carbon sinks and on a greater scale.
- Construct an explanation for how there was enough matter and energy in the peat/permafrost system for a zombie fire to burn under ice.
- Plan and carry out investigations to identify changes in matter and energy under different conditions in the system.
- Design a solution to balance matter and energy in a community students care about.

Building Toward NGSS Performance Expectations

HS-ESS2-6:

Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ESS3-6:

Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

HS-ETS1-2:

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-LS1-5:

Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-LS1-6:

Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

HS-LS1-7:

Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in the new compounds are formed resulting in a net transfer of energy.

HS-LS2-3:

Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

HS-LS2-4:

Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

HS-LS2-5:

Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

UNIT STORYLINE

Unit Question: What causes fires in ecosystems to burn and how should we manage them?

How students will engage with each of the phenomena



Lesson Set 1: What causes zombie fires to burn under the ice and what are the consequences?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 3 days How can fires burn under ice and release so much energy and matter? Anchoring Phenomenon 	 <i>Fires in the Arctic are burning under ice.</i>	We do a visual inquiry to investigate zombie fires. We share our experiences and ideas about how our lives are connected to fires. We develop initial models to explain the interactions in the zombie fire system and how they release so much carbon. We develop a DQB and decide to investigate how zombie fires could be burning under the ice. We figure out: • Zombie fires burn under ice throughout the winter. • In zombie fires, peat is burning in the thawing permafrost. • Lots of carbon is put into the air when these zombie fires burn. • Zombie fires are not very common but are becoming more common.	

↓ Navigation to Next Lesson: We figured out zombie fires burn under ice and release carbon. We wonder what is happening with the matter and energy in the peat/permafrost that allows fires to burn under ice.

LESSON 2

Lesson Set 1

2 days

What is peat and why does it burn so much?

Investigation

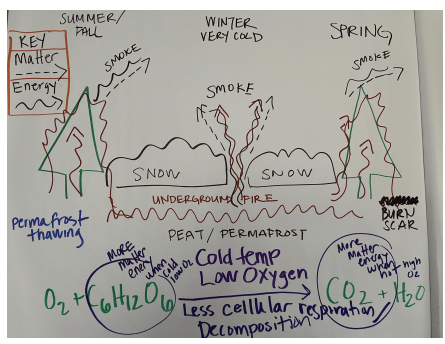
Burning peat and other fuels releases carbon dioxide and energy.

We decide to investigate what is burning in zombie fires. We observe and burn peat and other fuels for fire. We read about the relationships between permafrost and peat and notice and wonder about why peat formed. We figure out:

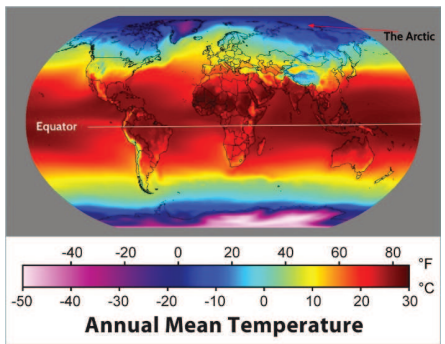
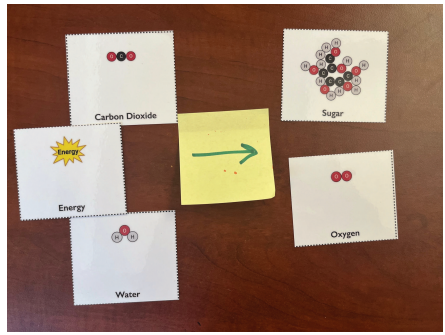
- We can explain puzzling observations using energy and matter concepts.
- Peat, made from ancient plants, is widespread and used as fuel.
- Peat is carbon-based and releases CO₂ when burned.
- Peat burns slowly, emitting much CO₂ and energy.
- Permafrost is ground that stays frozen for years, even centuries.
- Arctic permafrost thaw reveals peat.

		Peat	Wood	Leaves
Energy	Fuel temp before	25.7 °C	26.1 °C	25.5 °C
	Fuel temp after	41.3 °C	30 °C	25.9 °C
	Surrounding temp before	25.3 °C	25.4 °C	22.5 °C
	Surrounding temp after	26.8 °C	26.8 °C	25.8 °C
Matter	Burning time	10 min +	4 min	30 seconds
	Other observations	Hard to light. No visible flame, just a glowing ember at the beginning.	Difficult to keep lit. Short bright orange flame, went out before lid was on.	Easy to light. Tall bright yellow flame. Burned for 30 seconds.
	Mass before	0.48 grams	0.48 grams	0.48 grams
	Mass after	0.04 grams	0.23 grams	0.28 grams
Other observations	BTB before	Blue	Blue	Blue
	BTB after	Green / Yellow	Blue / Yellow	Blue / Yellow
	Other observations	Lots of smoke, condensation. Glass cover became cloudy and covered in droplets. Sample continued burning while taking mass after. Before was black, turned into a gray/white ash.	Was brown then turned black, then gray/white. After about 8 minutes, the sample seemed to clear out of the glass container.	Brown, then black. Very little smoke because the fire went out quickly.

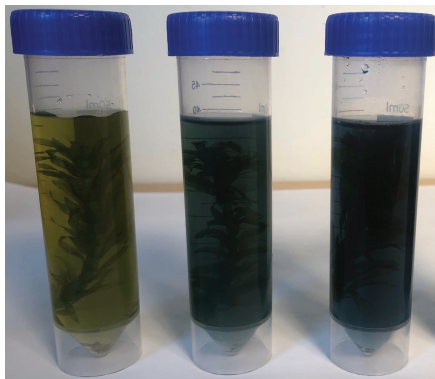
↓ Navigation to Next Lesson: We figured out peat is made of layers of dead plants and releases CO_2 when it burns. We wonder why those plants did not break down and what happens when peat forms.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 Lesson Set 1 4 days Why is there so much peat that has not decomposed in the permafrost? Investigation 	 <i>Peat does not decompose very much in permafrost.</i>	We look at images, develop models, and investigate how temperature affects decomposition rate. We plan and carry out an investigation, using yeast to generate evidence for an explanation about why there is so much peat. We figure out: - Energy and matter from plants are typically returned to the atmosphere by decomposers. - Conditions such as temperature and oxygen levels affect the rate of decomposition. - The mechanism of decomposition is cellular respiration. - Energy from sugar is transferred to yeast and other decomposers during cellular respiration. - Matter from sugar is transformed during cellular respiration to grow more yeast and produce carbon dioxide and water. - In the permafrost/peat system, cold temperatures and low oxygen levels slow the rate of decomposition and cellular respiration. - When rates of decomposition are low, the matter and energy do not flow out of the permafrost/peat system, making a carbon sink.	

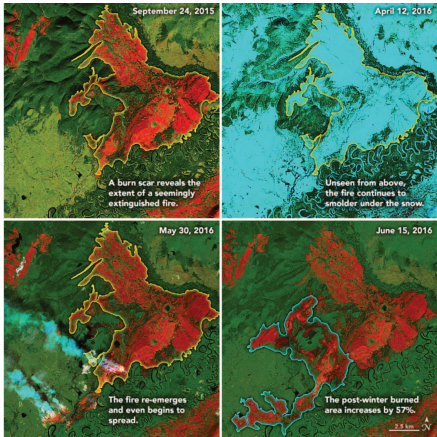
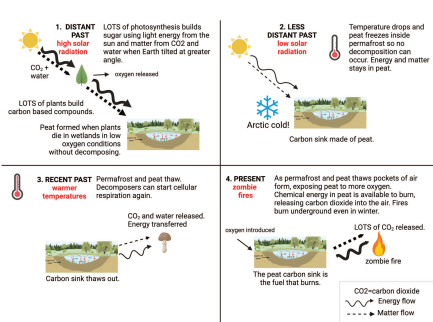
↓ **Navigation to Next Lesson:** We figured out that carbon and energy are trapped in permafrost/peat due to slow decomposition/respiration. We wonder why there were so many plants in the Arctic that made peat if it is so cold.

LESSON 4 Lesson Set 1 1 day How did so much plant energy and matter get into the peat in the zombie fire system? Problematising, Investigation 	 <i>Solar energy in the Arctic provides energy for photosynthesis.</i>	We investigate how so much plant matter was stored as peat under the permafrost. We read about Earth's conditions thousands of years ago that allowed for the formation of all of that peat. We figure out: - Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds through photosynthesis. - As solar radiation in the Arctic decreased, many plants died, and peat and permafrost were formed.	
---	---	--	--

↓ **Navigation to Next Lesson:** Now that we see that there is a relationship between solar radiation and photosynthesis, we need to investigate this. We need data!

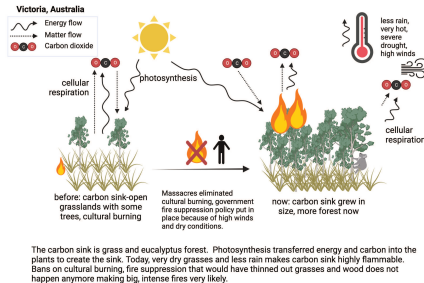
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it																				
LESSON 5 Lesson Set 1 3 days Could changes in the Earth's tilt cause more energy and matter to be stored in plants? Investigation 	 Plants make different amounts of starch when the light angle changes.	We plan and carry out an investigation to determine how differences in available solar energy impact how much carbon dioxide is captured and stored as chemical energy in plants. We figure out: - Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds. - As solar radiation in the Arctic decreased, plants died, and peat and permafrost were formed. - Through photosynthesis, plants convert carbon dioxide and water into sugar and release oxygen. - More solar energy means more carbon dioxide is captured and stored by plants as sugar and oxygen. - Plants convert excess sugar into larger carbon-based molecules, such as starch.	<table><tr><th></th><th colspan="2">Uncovered</th><th colspan="2">Covered</th></tr><tr><th></th><th>Before</th><th>After</th><th>Before</th><th>After</th></tr><tr><td>Indirect Light</td><td>Yellow</td><td>Green/Blue</td><td>Yellow</td><td>Yellow</td></tr><tr><td>Direct Light</td><td>Yellow</td><td>Dark Blue</td><td>Yellow</td><td>Yellow</td></tr></table>		Uncovered		Covered			Before	After	Before	After	Indirect Light	Yellow	Green/Blue	Yellow	Yellow	Direct Light	Yellow	Dark Blue	Yellow	Yellow
	Uncovered		Covered																				
	Before	After	Before	After																			
Indirect Light	Yellow	Green/Blue	Yellow	Yellow																			
Direct Light	Yellow	Dark Blue	Yellow	Yellow																			

↓ **Navigation to Next Lesson:** We figured out that changes in solar energy based on differences in the Earth's tilt are responsible for the matter and energy stored in peat under the permafrost. We think we have figured out enough to try to explain how zombie fires can burn under ice and release so much carbon.

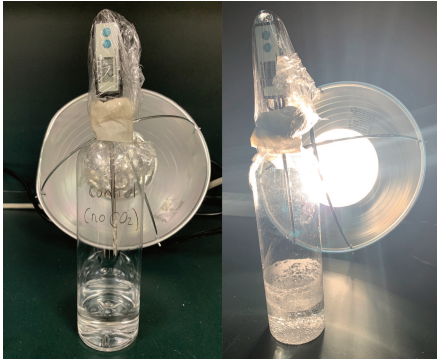
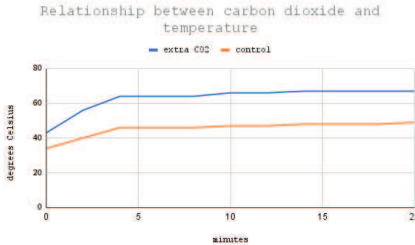
LESSON 6 Lesson Set 1 2 days How do zombie fires disrupt the flow of energy and cycle of matter in Arctic ecosystems? Putting Pieces Together 	 <i>An infrared image shows the heat energy of a zombie fire burning underground.</i>	We develop our class consensus model based on evidence we collected to construct an explanation for zombie fires. We return to our DQB to update our questions and revise our Driving Question: What causes fires in ecosystems to burn? We figure out: - Photosynthesis captures energy from sunlight and converts to chemical energy in carbon-based glucose fuel, taking carbon out of the air and into the plants. Plants with extra energy and matter, assemble glucose into larger molecules. - Plants in the Arctic die and get submerged where it is too cold for decomposition to happen quickly. Generations of plants die on top of one another resulting in more and more matter and energy remaining underwater/ice. - Peat is layers of partially decomposed plants. When permafrost thaws, peat is exposed. Peat can now decompose and burn. - Zombie fires burn carbon sinks in the peat/permafrost system releasing tons of CO₂. - In the recent past, peat was frozen in permafrost, keeping matter and energy, but if in the future more permafrost thaws, then more matter and energy will be available.	 <i>Illustrations created by OpenSciEd in BioRender</i>
--	--	--	--

↓ **Navigation to Next Lesson:** We figured out how zombie fires are burning in the Arctic, but we wonder if there are other ecosystems with carbon sinks burning and what makes them vulnerable to burn.

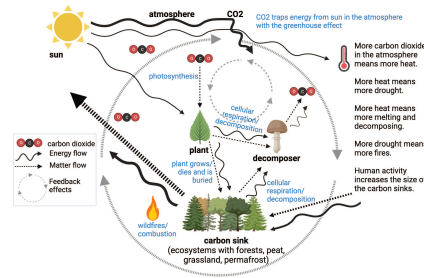
Lesson Set 2: How is global carbon cycling affected by fires?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 7 Lesson Set 2 2 days What is happening to carbon sinks in other ecosystems? Investigation 	 <i>Fires are burning in carbon sinks around the world.</i>	We use case studies to investigate places, lands, and waters where global carbon sinks are burning with more frequency. We analyze how energy and matter are moving through each system and discuss the historical events and decisions that contributed to the current conditions that make each carbon sink more likely to burn. We develop small-group models to help us come to consensus on the conditions that make carbon sinks more likely to burn. We wonder what the consequences and large-scale impacts are of fires from all of these ecosystems. We also wonder about ways to manage fires into the future. We figure out: - Many different ecosystems have carbon sinks created from the flow of energy and matter into plants by photosynthesis. - There are common climate-related and human-caused factors in ecosystems that make the energy and matter in carbon sinks more likely to burn. - Fire increases the flow of matter and energy from the biosphere to the atmosphere.	 <i>Illustrations created by OpenSciEd in BioRender</i>

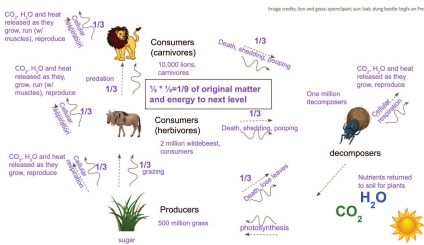
↓ **Navigation to Next Lesson:** We figured out carbon sinks are burning due to drought, rising temperatures, land use changes, and fire suppression. We wonder about the larger consequences for all of these fires.

LESSON 8 Lesson Set 2 2 days Why should we be concerned that carbon sinks around the world are burning? Investigation 	 <i>Carbon dioxide from fires in the atmosphere is causing the temperature to increase.</i>	We investigate the effect of increased carbon dioxide on temperature, develop directional hypotheses, and collect evidence to support our hypotheses. We revise our hypotheses to explain the relationship between atmospheric carbon dioxide and temperature at the global scale and investigate data collected by scientists. We figure out: - Increased carbon dioxide in the air causes increased air temperature. - A directional hypothesis explains the effect of carbon dioxide concentration on temperature in a simulated system. - Global data indicates the relationship we figured out in our investigation system is similar to the relationship at the global scale.	
---	--	--	--

↓ **Navigation to Next Lesson:** We figured out that increasing atmospheric carbon dioxide increases temperature and wonder how the relationship between carbon dioxide and temperature affects other systems.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it												
LESSON 9 Lesson Set 2 2 days What are the global effects of increased carbon dioxide from fires? Investigation, Putting Pieces Together 	Atmosphere <table><tr><th>Dice roll</th><th>What happens?</th><th>Where to next?</th></tr><tr><td>1 - 2 - 3</td><td>You remain in the atmosphere as a molecule of carbon dioxide, CO₂ (matter). Energy remains in the same arrangement of atoms. Record this action and roll again.</td><td>Atmosphere</td></tr><tr><td>4</td><td>You enter the ocean as carbon dioxide, CO₂, and are dissolved in the water (matter). Energy flows to a new system in the same arrangement of atoms.</td><td>Ocean</td></tr><tr><td>5 - 6</td><td>You are taken in by a producer as carbon dioxide, CO₂. The producer uses energy from sunlight and water to rearrange you into molecules used to build biomass (matter) of the producer. Energy flows to a new system AND the atoms are rearranged.</td><td>Producers</td></tr></table> Fire influences how carbon and energy cycle through Earth's systems differently than in the past.	Dice roll	What happens?	Where to next?	1 - 2 - 3	You remain in the atmosphere as a molecule of carbon dioxide , CO ₂ (matter). Energy remains in the same arrangement of atoms. Record this action and roll again.	Atmosphere	4	You enter the ocean as carbon dioxide , CO ₂ , and are dissolved in the water (matter). Energy flows to a new system in the same arrangement of atoms.	Ocean	5 - 6	You are taken in by a producer as carbon dioxide, CO ₂ . The producer uses energy from sunlight and water to rearrange you into molecules used to build biomass (matter) of the producer. Energy flows to a new system AND the atoms are rearranged.	Producers	We use a quantitative model to simulate how carbon and energy flow through Earth's systems. We develop a model to determine if carbon dioxide levels and temperature will continue to grow as more carbon sinks burn. We figure out: - Human actions caused the burning of carbon sinks, which shifted the balance of carbon (matter) and energy in the Earth system, releasing energy and matter from plant-based carbon sinks from the biosphere into the atmosphere. - A (positive) feedback effect is created as increased carbon dioxide causes increased temperature and increased temperature causes more drought, which leads to more wildfires that release additional carbon dioxide into the atmosphere.	 Illustrations created by OpenSciEd in BioRender
Dice roll	What happens?	Where to next?													
1 - 2 - 3	You remain in the atmosphere as a molecule of carbon dioxide , CO ₂ (matter). Energy remains in the same arrangement of atoms. Record this action and roll again.	Atmosphere													
4	You enter the ocean as carbon dioxide , CO ₂ , and are dissolved in the water (matter). Energy flows to a new system in the same arrangement of atoms.	Ocean													
5 - 6	You are taken in by a producer as carbon dioxide, CO ₂ . The producer uses energy from sunlight and water to rearrange you into molecules used to build biomass (matter) of the producer. Energy flows to a new system AND the atoms are rearranged.	Producers													

↴ **Navigation to Next Lesson:** We figured out burning carbon sinks creates a positive feedback effect between carbon dioxide and temperature and wonder if we can reduce this by managing carbon sinks better.

Lesson Set 3: How do we design solutions to manage the impacts of fires?			
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 10 Lesson Set 3 3 days How can we help manage the matter and energy in fire systems? Investigation 	 <i>Successful management of carbon sinks to prevent large wildfires uses a variety of methods that affect the flow of carbon and energy in ecosystems.</i>	We investigate four case studies of successful fire management. We read about how prescribed burning, cultural burning, restoring grazer populations, and replanting forests help manage the amount of available carbon and energy that burn in wildfires. We use a mathematical representation to explain how these techniques could help fire management in ecosystems. We investigate fire risk in our own community and ways to reduce that risk. We figure out: - Managing the amount of fuel available to burn in carbon sinks through prescribed burns, cultural burns, and grazing helps reduce an overabundance of built-up energy and matter. - Planting trees can remove carbon dioxide from the atmosphere and has the potential to reduce atmospheric temperature. - Energy and matter flow through each level of a food web through producers, consumers and decomposers.. - Fire management decisions have short- and long-term consequences for both social and ecological structures and systems.	 <i>OpenClipart; Ivak; brgfx on Freepik</i>

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

↓ **Navigation to Next Lesson:** We figured out successful fire management includes a balance of plants and animals. We wonder how we can protect the places, lands, and waters we care about.

LESSON 11

Lesson Set 3

3 days

What decisions can we make to help manage fire in communities we care about?

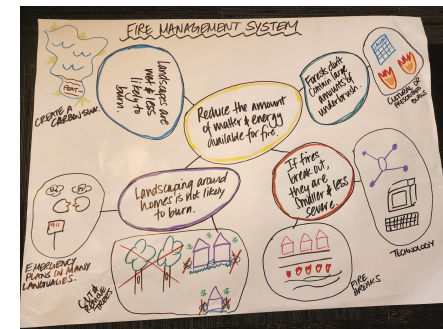
Putting Pieces Together



Fire management systems must meet criteria, constraints, and community needs.

We create fire, matter, and energy management systems for reducing carbon emissions for places, lands, and waters we care about. We acknowledge species, kinds, and behaviors at different scales of the ecosystem we want to protect. We break down fire management criteria into simpler criteria. We share and seek knowledge from our community members. We share and revise fire matter and energy management systems, putting pieces together from the unit connected to five dimensions of complex socio-ecological systems. We figure out:

- Criteria need to be broken down into simpler ones to manage fire to see who will be impacted (human and nonhuman) by our decisions.
- Making decisions involves and impacts people at many levels in the systems we care about.
- The places, lands, and waters we care about are complex, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
- We can answer many questions on our DQB.



↓ **Navigation to Next Lesson:** We figured out it is helpful to break down criteria when designing fire management systems. We wonder if we can apply what we figured out to a new phenomenon.

LESSON 12

Lesson Set 3

1 day

Can we use everything we have figured out about fires to explain a new phenomenon?

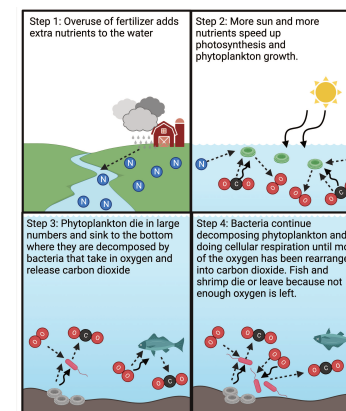
Putting Pieces Together



Massive fish kills happen in the Gulf of Mexico.

We complete a Transfer Task about eutrophication in marine ecosystems to demonstrate how what we figured out throughout the unit about the flow of energy and matter applies to other systems. We figure out:

- Carbon and oxygen cycle in systems such as the Gulf of Mexico, including the hydrosphere, atmosphere, and biosphere.
- Factors such as temperature and nutrient availability affect components of the system and can be observed through inputs and outputs of photosynthesis and carbon dioxide.



Illustrations created by OpenSciEd in BioRender

↓ **Navigation to Next Lesson:** This is the last lesson in the unit.

LESSONS 1-12

28 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements For Science Investigations

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

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

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

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

Please follow these lab safety recommendations for any science investigation:

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



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

This unit is the second in the OpenSciEd High School Biology course sequence. It is designed to build on student ideas about ecosystem interactions from the course's first unit, *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. In the first unit of OpenSciEd HS Biology, students developed conservation plans driven by five big ideas that students figured out and use to inform their plans: 1) Natural and human-caused disruptions can have short- and long-term impacts on ecosystems. 2) The stability of ecosystems is influenced by the current ecosystem state, biodiversity, and intensity or longevity of disturbances. 3) Ecosystems have carrying capacities that are impacted by the availability of resources, spatial and temporal factors, and the behaviors and interactions of different nonhuman and human populations. 4) Group behaviors like migration, hunting in packs, and prioritizing the protection of young organisms can increase the chances of survival. 5) Conservation involves benefits and burdens that are influenced by the complexity of ecosystem components and interactions.

In the units that follow this one (*OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*, *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)*, and *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes? (Speciation Unit)*) students learn about genetics through cancer, natural selection through urbanization, and speciation throughizzly bears. Students will use their knowledge of matter and energy in systems from these first two units to look more closely at changes within individuals and populations of organisms over time.

What is the anchoring phenomenon and why was it chosen?

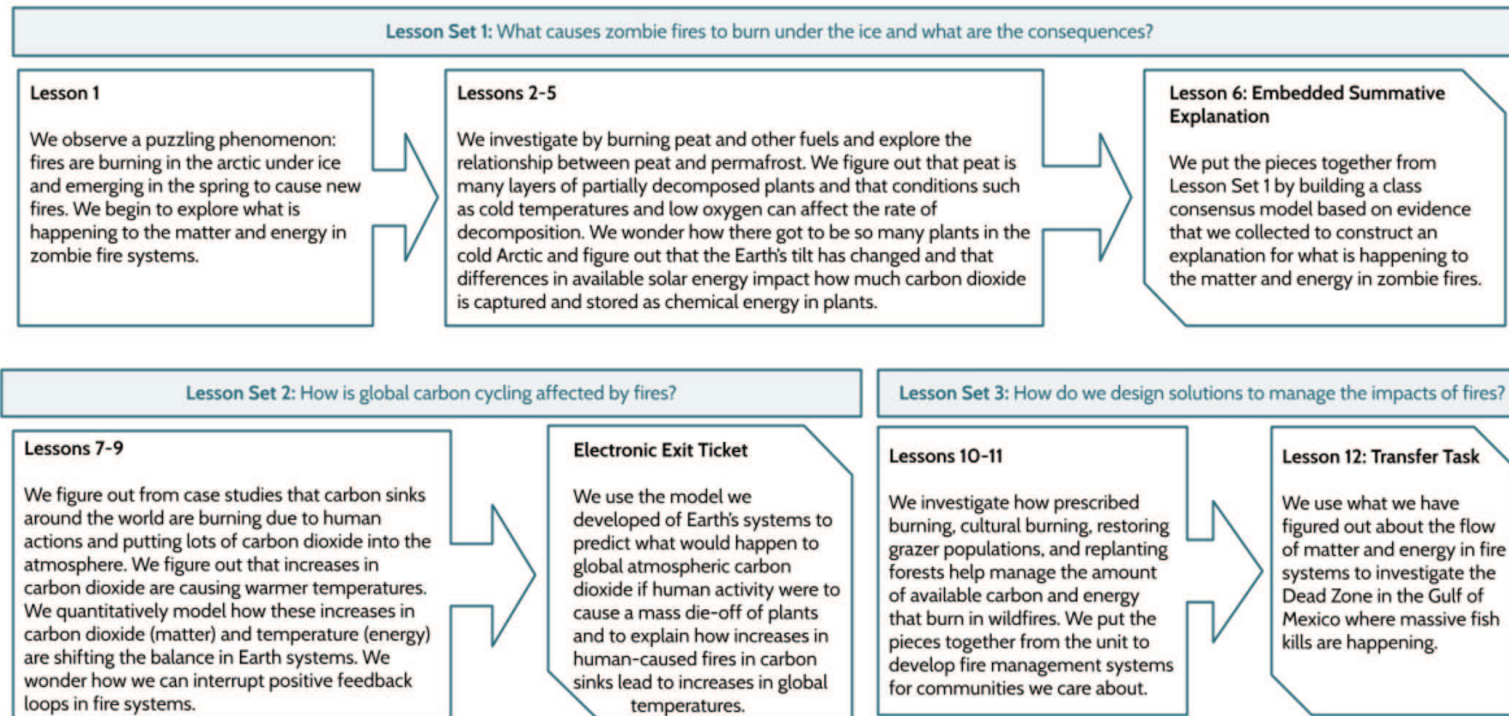
This unit is anchored by a puzzling Earth science phenomenon: fires are burning under ice and snow in the Arctic. Scientists in Alaska discovered burn scars from fires appearing very close to each other, and that spring fires were starting very early in the year. Locals discovered smoke emerging from under the snow and ice in Yakutia, Siberia. At the same time, scientists and local people noticed changes in the permafrost. It was thawing, cracking, and falling apart. Once living things that had been trapped in ice for thousands of years became exposed to air and warmth. As these overwinter, or zombie fires burn, scientists measured massive amounts of carbon dioxide and other gasses being released into the atmosphere. This phenomenon provides the context in which to investigate the relationship between matter and energy within smaller-scale systems, ecosystems, and global-scale systems.

The zombie fire phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to almost 3,000 students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. The zombie fire phenomenon was chosen for the following reasons:

- Students showed high interest in explaining fires in survey data.
- It provides a diverse suite of entry points for students across the unit to make local, cultural, and/or relevant community connections so that students' background knowledge and frames of reference are assets for their sensemaking work.
- Teachers and administrators saw the phenomenon as interesting and on grade band.
- Explaining the phenomenon addresses all the DCIs in the bundle at a high school level.
- Explaining the phenomenon requires the use of both energy and matter in order to understand changes in ecosystems from an atomic to a global scale.

How is the unit structured?

The unit is organized into three main lesson sets. **Lesson Set 1** (Lessons 1-6) focuses on answering the question: *What causes zombie fires to burn under the ice, and what are the consequences?* In the first lesson set, students investigate what is happening when zombie fires burn in the peat/permafrost system, what peat/permafrost is, why there is so much peat, and how there can be so many plants in the Arctic that could become peat. **Lesson Set 2** (Lessons 7-9) focuses on answering the question: *How is global carbon cycling affected by fires?* In the second lesson set, students apply their new ideas about the matter and energy flow in the peat/permafrost system to other fire-vulnerable carbon sinks and then to the global effects of increased carbon due to fires. **Lesson Set 3** (Lessons 10-12) focuses on answering the question: *How do we design solutions to manage the impacts of fires?* The unit culminates by instilling hope in students through investigations of successful fire management and designing a system for fire management in a community they care about.



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

This unit is designed to support students in developing an understanding of **how matter and energy flow in organisms, ecosystems, and Earth's spheres** in a relevant context. **Developing and using models** is intentionally developed beginning in Lesson 1 as students **develop a model to explain how matter (peat) and energy (fire)** flow in the zombie fire system. The scientific practices are interwoven with the crosscutting concepts of **systems and system models** and **energy and matter** throughout the unit. These **models** are revised over time, with complexity added as they work from small-scale **chemical processes of photosynthesis and cellular respiration**, to large-scale processes that **move energy and matter** between Earth systems, in particular the **biosphere and atmosphere**.

Planning and carrying out investigations is intentionally developed beginning in Lesson 2, when students figure out ways to **plan and conduct an ethical, safe investigation** to help them figure out how so much **matter and energy** is stored in peat and permafrost in the Arctic.

Constructing explanations and designing solutions is intentionally developed throughout the unit. Students **use the evidence** collected in their **own investigations along with data from additional sources** to explain **how matter and energy flow** through the zombie fire system in Lesson Set 1. In Lesson Set 2, they **apply scientific ideas** of how **matter and energy transfer in ecosystems** to **evaluate and design real-world solutions** for interrupting **the flow of matter and energy in carbon sinks** available to burn in communities of concern to them.

This unit builds toward these performance expectations:

HS-LS1-5: Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-LS1-6: Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

HS-LS1-7: Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.

HS-LS2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

HS-LS2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-ESS2-6†: Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ETS1-2†: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

*This performance expectation is developed across multiple OpenSciEd Biology units.

†This performance expectation is developed across multiple OpenSciEd courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
This unit intentionally develops students' engagement in these practice elements: Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop a complex model that allows for manipulation and testing of a proposed process or system. Planning and Carrying Out Investigations • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. • Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. • Select appropriate tools to collect, record, analyze, and evaluate data. • Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. Constructing Explanations and Designing Solutions: • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. • Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.	LS1.C: Organization for Matter and Energy Flow in Organisms • The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5) • The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6) • As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7) • As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. (HS-LS1-7) LS2.B: Cycles of Matter and Energy Transfer in Ecosystems • Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. • Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. (HS-LS2-4)	This unit intentionally develops students' engagement in these crosscutting concept elements: Systems and Systems Models • Systems can be designed to do specific tasks. • Models (e.g., physical, mathematical, computer mo/dels) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. 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. • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. • Energy drives the cycling of matter within and between systems. The following crosscutting concepts are also key to the sensemaking in this unit: • Cause and Effect

Elements from the following practices are also key to the sensemaking in this unit: • Asking Questions and Defining Problems • Mathematics and Computational Thinking • Obtaining, Evaluating, and Communicating Information	• Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (HS-LS2-5) PS3.D: Energy in Chemical Processes • The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. (secondary)(HS-LS2-5) ESS2.D: Weather and Climate • Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6) ETS1.C: Optimizing the Design Solution • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS 1-2)
--	--

Disciplinary Core Ideas are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. DOI: <https://doi.org/10.17226/13165>. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

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

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Scientific Investigations Use a Variety of Methods. Science investigations use diverse methods and do not always use the same set of procedures to obtain data.	Students plan and carry out investigations in Lessons 2, 3, 5, and 8. These investigations have different methods and procedures.
Scientific Knowledge is Based on Empirical Evidence.	In Lessons 2, 3, 5, and 8, students use empirical evidence to create models of yeast systems to investigate cellular respiration and to establish the relationships between variables to explain the flow of matter and energy in systems.
Scientific Knowledge is Open to Revision in Light of New Evidence. Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	The unit gives many opportunities for students to revise their models with new ideas and evidence. Initially, models illustrate the interactions in the zombie fire system in the Arctic and how they release so much carbon into the atmosphere. These ideas are then revised in Lesson 6, where models show the flow of energy and matter throughout the zombie fire system, taking into account photosynthesis and cellular respiration at different scales. Then these models are revised and expanded in Lesson 9 to show that the Sun's and wildfires' energy drives carbon cycling and that increasing atmospheric carbon is increasing global temperatures explaining climate change which is one of the causes of zombie fires in the first place.

Scientific Knowledge Assumes an Order and Consistency in Natural Systems. Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.	In Lesson 4, students come to understand that the amount of solar radiation that hits the surface of the Earth has changed since 10,000 years ago. The increase of the angle of only 2° was enough of a change to increase the amount of energy to hit the surface of the Earth to produce the peat (matter) in the Arctic. In Lesson 6, students bring together all of the ideas to update their consensus models to explain that in the past the peat was frozen under the permafrost but as temperatures increase, the permafrost thaws making the peat available to burn in zombie fires. Students make predictions based on trends that temperatures will continue to increase, permafrost will continue to thaw, and more peat will be available to burn. Students take what they understand about the flow of energy and matter and other fire management policies in Lesson 11 to create fire management systems for communities that they care about that they propose will balance the flow of energy and matter and to protect the humans and non humans of the ecosystem in the future.
Science is a Human Endeavor. Science and engineering are influenced by society and society is influenced by science and engineering.	As society is changing how land is used and how natural resources are managed, it requires innovative ways of applying science and engineering tools for the management of these systems. Lesson 7 explores how people are influencing the health of several carbon sinks globally, making them vulnerable to wildfires, thereby affecting life for humans and more-than-humans in these places. Lesson 10 explores different approaches to fire management that encompass traditional ways of knowing alongside engineering and technology in various sites around the world. In Lesson 11, students design more inclusive fire management systems by balancing the criteria, constraints, and trade-offs to more effectively protect ecosystems they have a connection to.

Connections to Engineering, Technology, and Applications of Science (ETS)	
Which elements of ETS are developed in the unit?	How are they developed?
Influence of Engineering, Technology, and Science on Society and the Natural World. New technologies can have deep impacts on society and the environment, including some that were not anticipated.	In Lesson 7, students investigate case studies about how changes in land use have made carbon sinks susceptible to wildfires as societal needs and technological advances put more pressure on the management of natural resources.
Influence of Engineering, Technology, and Science on Society and the Natural World. Modern civilization depends on the major technological systems, such as agriculture, health, water, energy, transportation, manufacturing, construction, and communications.	In order to balance the flow of energy and matter in different levels of ecosystems, students explore the role of prescribed burning, adding grazers, and planting trees in fire management to prevent the devastation we have seen from big wildfires historically (Lesson 10).

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

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

- MS-LS1.C: Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy.
- MS-LS2.B: Food webs are models that demonstrate how matter and energy are transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter

back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.

- **MS-PS3.D:** The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen (secondary). Cellular respiration in plants and animals involves chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.
- **MS-ESS2.D: Weather and Climate.** Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.
- **MS-ESS3.D:** Human activities, such as the release of greenhouse gasses from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities.
- **MS-ETS1.B:** There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.
- **MS-PS1.A: Structure and Properties of Matter.** Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. In a liquid, molecules are constantly in contact with others.
- **MS-PS1.B: Chemical Reactions.** Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change. Gasses and liquids are made of molecules or interim atoms that are moving about relative to each other.
- **MS-PS3.A: Definitions of Energy.** The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule.

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

- **HS-LS2.A: Interdependent Relationships in Ecosystems:** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. (HS-LS2-1),(HS-LS2-2)
- **HS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience:** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to more or less its original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. (HS-LS2-2),(HS-LS2-6)
- **HS-LS4.D: Biodiversity and Humans:** Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem function and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (HS-LS2-7)

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

- **ETS1.C: Optimizing the Design Solution-** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (*Oysters Unit, Vehicle Collisions Unit*)
- **ESS2.D: Weather and Climate-** Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (*Oysters Unit, Polar Ice Unit*)
- **LS1.C.2: Organization for Matter and Energy Flow in Organisms-** The sugar molecules thus formed contain carbon, hydrogen, and oxygen. Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (*OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*)

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

Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
-----------	--------	----------------	------	------	-------------	----------	-----------

Biology	<i>Cancer Unit</i>	<i>Serengeti Unit, Fires Unit</i>	<i>Fires Unit, Natural Selection Unit</i>	<i>Natural Selection Unit, Cancer Unit</i>	<i>Serengeti Unit</i>	<i>Fires Unit, Cancer Unit, Natural Selection Unit</i>	<i>Speciation Unit</i>	<i>Cancer Unit, Speciation Unit</i>
Chemistry	<i>Polar Ice Unit, Oysters Unit</i>	<i>Electrostatics Unit, Space Survival Unit</i>	<i>Polar Ice Unit</i>	<i>Fuels Unit</i>	<i>Polar Ice Unit, Oysters Unit</i>	<i>Fuels Unit</i>	<i>Fuels Unit</i>	<i>Electrostatics Unit, Space Survival Unit</i>
Physics	<i>Electricity Unit, Cosmology Unit</i>	<i>Electricity Unit, Microwave Unit</i>	<i>Microwave Unit</i>	<i>Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit</i>	<i>Vehicle Collisions Unit, Meteors Unit</i>	<i>Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit</i>	<i>Vehicle Collisions Unit</i>	<i>Cosmology Unit, Microwave Unit</i>

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

What are some common ideas that students might have?

Students will come into the unit with many ideas about matter and energy in systems derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with living things, and the conversations they have had with parents, friends, and family members.

Some relevant ideas that students may come into the unit with include the following:

- Energy flows from producers to consumers to decomposers in an ecosystem.
- Consumers use the energy they consume to grow and survive.
- Decomposers break down material for energy and return materials to the Earth for producers to use as inputs.
- There are many decomposers that you cannot see, but you can measure their activity.
- Carbon exists in different forms and amounts all over the planet.
- Fires have natural and artificial causes.
- Cellular respiration involves using oxygen to break down food to release energy, water, and carbon dioxide.
- Plants use sunlight and carbon dioxide to make sugar that gets used or stored.
- The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen.
- Plants use the energy from light to make sugars (food) from carbon dioxide in the atmosphere and water through the process of photosynthesis, which releases oxygen. These sugars can be used immediately or stored for growth or later use.
- Humans contribute carbon dioxide to the atmosphere by burning fossil fuels.

- Increasing atmospheric temperatures can cause drought.
- Carbon dioxide emissions from burning fossil fuels are a cause of change, including more frequent droughts.
- Designing precise criteria and constraints is important to designing solutions.

It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it also improves science learning. For example, in Lesson 4, students explore what it was like in the Arctic when the Earth's tilt was different. It may be difficult for students to grapple with a place that is now cold and icy having an abundance of tropical plants that could become something like peat. However, they might have experience with growing plants where they live, at school, or in the community. Building explicitly from these ideas to draw connections is a productive pedagogical tool that will help students construct a new, more accurate conceptual model for how energy capture contributes to the global cycling of carbon.

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

This is the second unit of the High School Biology Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching this unit earlier in the Biology course. These include the following adjustments:

- If taught before *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* or at the start of the school year, be sure to include these supports: supplemental teaching of community agreements and setting up the Driving Question Board. These supports are built into the *Serengeti Unit* and could be adapted accordingly for this unit if needed.
- If taught earlier in the school year, supplemental teaching around the components, interactions, and mechanisms between organisms in ecosystems and how to represent it may be required.

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

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

- Lesson 8: Have students begin discussions of how they will represent their data during data that developing them is a quicker transition.
- Lesson 10: If you are short on time, assign the investigation of a community of choice as part of the home learning. Students can complete the investigation with members of the community and discuss their findings when they return.
- Lesson 12: If you are short on time or benefit from being presented with information in smaller chunks, consider waiting to hand out *Nitrogen Pollution By State* until students reach that part of the assessment or not using it entirely (and cross off or deleting the text for question 12 that suggests using it).

To extend or enhance the unit, consider the following:

- Lesson 3: For students who do not have a middle school understanding of matter and energy flow through decomposition, it may be helpful to take extra time to review these concepts. *Optional: Banana Investigation* is provided as an optional investigation. Students will use photos of decomposing banana peels placed in different environments (open air, sealed in a bag with water, in soil, in a freezer) to make observations about changes they see over a 5-day period. Additional support for teaching about decomposition and cellular respiration at the middle school grade band is available in *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)* and *OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*. If students need support developing their middle school level planning and carrying out investigation practice, refer to *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*.
- Lesson 3: High-interest students may be motivated to know more about the structure of sucrose and its relationship to glucose.
- Lesson 3: If students are motivated to go beyond the standards in this lesson, an optional reading *Frozen in Time* is available to extend their thinking about decomposition in peat that supports students in understanding other factors that contribute to peat being an effective carbon sink, such as pH, as the sphagnum moss that is the most abundant organic matter in peat creates acidic conditions in the peat, thereby making the environment less desirable for decomposers.
- If students need support developing their middle school-level planning and carrying out investigation practice, refer to *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*.
- Lesson 7: There are complex histories that lead up to all of the events that occur in each case study presented. However, the lesson does not have time to pursue all of the details behind government policies and decisions involved. Students interested in pursuing more details about the human actions discussed should be encouraged to read more from the references provided at the end of each case study. Have students research supporting Indigenous rights, climate advocacy, and making sustainable choices to begin addressing some of the harm done to these communities.
- Lesson 8: By this time in the unit, students may be inquiring about how they can make different choices that could reduce the amount of carbon that they produce with their lifestyle (carbon footprint) and inspire student agency.
 - Share EnergyStar.gov's Carbon Footprint resources for students to collect baseline data to measure the impact of their decision-making (with their community members) on the flow of carbon in their area. https://www.energystar.gov/ia/products/globalwarming/downloads/GoGreen_Activities%20508_compliant_small.pdf
 - Digital version that shares facts and figures, assesses feelings around the results with suggestions on how to relate those feelings to action, opportunities to explore your data, and potential solutions to reduce the number of Earths that are necessary for your lifestyle/personal Overshoot Day: <https://www.footprintcalculator.org/home/en>
- Lesson 9: If students want to better understand the relationship between photosynthesis and global atmospheric carbon dioxide levels, ask them to look at the patterns found in the data from the Mauna Loa Observatory. This shows that plants can cause seasonal fluctuations on a large scale. Play the animation at <https://gml.noaa.gov/ccgg/trends/history.html> (from the beginning until 1:36) or look at the static image of the data at <https://gml.noaa.gov/ccgg/trends/>.
- Lesson 10: For students interested in cultural burning practices that follow up on *California's Carbon Sink*, the Karuk Nation has a series of short videos about their programs. <https://vimeo.com/458221338>
- Lesson 11: If your students are interested in an additional historical example of a fire management system, investigate *Optional: Smokey Bear Campaign* to learn about the Smokey Bear campaign.
- Lesson 11: Spend additional time revising the proposed solutions and present them to decision-makers in the community who may be able to implement them.

- Lesson 11: Challenge students to research the latest fire management technology and include it in their solutions.

Additional guidance for extensions is given within each Teacher Guide.

What mathematics concepts will students engage with in the unit?

This unit requires knowledge of how to analyze and interpret information from data, graphs, and other representations. In addition, students will need to gather and represent data in ways that can help them identify patterns in investigation results.

This unit does not assume students are fluent with the mathematical practices listed below but that students develop these practices as part of the sensemaking. Thus, these standards are not so much prerequisites as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below.

Talk with the math teacher(s) to identify the strategies students are familiar with for modeling with mathematics and constructing graphical representations of data.

Category	Code	Domain and Heading	Standard	Lesson
n/a	SS.MATH.PRA CTICE.MP4	Mathematical Practice 4	Model with mathematics.	10
Number and Quantity	CCSS.MATH.CONT ENT.HSN.Q.A.1	Quantities: Reason quantitatively and use units to solve problems	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.	8
Number and Quantity	CCSS.MATH.CONT ENT.HS.N-Q.2	Quantities: Reason quantitatively and use units to solve problems	Define appropriate quantities for the purpose of descriptive modeling.	9

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

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

Many of these strategies are highlighted in the Teacher Guides in sidebar callout boxes with the headings of:

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

The example callout below highlights how an activity can be modified to support a wider variety of learners.

*** ATTENDING TO EQUITY- Universal Design for Learning:** If it is something familiar to your students or part of their education plans, consider allowing students to use a digital graphing tool such as a graphing calculator or spreadsheet software to help them create their graphs. Students can take the data table and enter it into graphing software. Allowing alternatives for use of tools such as a calculator can remove barriers for students in *expressing* their understanding by keeping the focus on the learning goal. Use of such tools can help provide a match between a student's abilities and the demands of the task.

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

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students in figuring out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the “Where we are going” and “Where we are not going” sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**LS1.C: Organization for Matter and Energy Flow in Organisms**, **LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** (Shared with *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*), **ESS2.D: Weather and Climate** (Shared with *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*), **ESS3.D: Global Climate Change** (Shared with *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*), **ETS1.C: Optimizing the Design Solution** (shared with *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and Performance Expectations for this unit:

- To learn more about the zombie fire phenomenon:
 - Zombie fires more frequent in Boreal Forests: <https://theconversation.com/zombie-fires-are-occurring-more-frequently-in-boreal-forests-but-their-impacts-remain-uncertain-198459>
 - Blazes That Refuse to Die: <https://www.nytimes.com/2021/05/19/climate/climate-change-zombie-forest-fires.html>
 - Video: Zombie Fires Are on the Rise: <https://www.youtube.com/watch?v=krkNjssZDHQ>
 - Video: News report on increased zombie fires: <https://www.youtube.com/watch?v=qF99NMwPCOM>
 - Zombie fires in Alaska and Siberia: <https://www.washingtonpost.com/weather/2020/05/28/zombie-fires-burning-arctic-siberia/>
- To learn more about the carbon cycle and climate change:
 - NASA visualization: <https://svs.gsfc.nasa.gov/5110>
 - NOAA History of Atmospheric Carbon Dioxide: <https://gml.noaa.gov/ccgg/trends/history.html>
- To learn more about fire management solutions from an Indigenous perspective:
 - Karuk Fire Management (California): <https://vimeo.com/458221338>
 - Dja Dja Wurrung Clan and Forest Fire Management of Victoria: <https://youtu.be/kKmRf6HEOFI>
 - Good Fire podcasts: <https://yourforestpodcast.com/good-fire-podcast>
 - PBS The Age of Nature, Episode 3: <https://wisconsin.pbslearningmedia.org/resource/full-program/the-age-of-nature-video-gallery/>

How do I support students' emotional needs?

In this unit, students explore the challenges associated with wildfires and climate change. These raise issues concerning colonization, destruction of land, decision-making, and animal welfare. Students may have emotional needs related to three main issues:

- Trauma associated with loss due to wildfires or other extreme weather events.
- History of colonization and the loss of tribal sovereignty. Students may feel guilt about past events leading to loss of land and life.
- Strong beliefs about animal well-being, such as protecting animals and their habitat from fire.

Before beginning this unit, make sure to reach out to the student health services staff at your school for student-specific support and strategies that might be needed in regard to the students in your classroom. Consider asking a member of the student health services staff to join you in the classroom at key moments, such as the introduction to zombie fires discussed in **Lesson 1**. Also consider planning follow-up check-ins with the counselor in regard to any students who may need additional emotional support. Details on specific strategies and supports are provided in *Trauma-Informed SEL Supports*.

Educate yourself about the impacts of wildfires in locations that may be of special concern to your students. Learn more about local initiatives to protect those areas from burning. Plan ahead with ways to support students. Consider the following resources:

- Learning for Justice: Critical Practices: <https://www.learningforjustice.org/frameworks/critical-practices>
- Christensen, A., C. Welton-Mitchell, A.U. Gold, L. James, and L. Zeitz. 2023. Beyond doom and gloom: Teaching climate change to foster empowerment. *Connected Science Learning* 5 (3). <https://www.nsta.org/connected-science-learning/connected-science-learning-may-june-2023/beyond-doom-and-gloom-teaching>
- Hickman, C., E. Marks, P. Pihkala, S. Clayton, E. Lewandowski, E. Mayall, B. Wray, C. Mellor, Susteren, L.V. 2021 Climate anxiety in children and young people and their beliefs about government responses to climate change: A global survey. *The Lancet Planetary Health* 5 (12). [https://doi.org/10.1016/S2542-5196\(21\)00278-3](https://doi.org/10.1016/S2542-5196(21)00278-3)
- Gislason, M. K., & Kennedy, A. M. (2022, Jan 27). *How to teach children about climate change, inspire hope and take action to change the future. The Conversation.* <https://theconversation.com/how-to-teach-children-about-climate-change-inspire-hope-and-take-action-to-change-the-future-174036>

- *The National Child Traumatic Stress Network. (2018, June 11). Effects of complex trauma. Retrieved October 16, 2023, from <https://www.nctsn.org/what-is-child-trauma/trauma-types/complex-trauma/effects>.*

Reach out to students' support systems at home before the unit using *Fires Home Communication*. This letter is a way to communicate with trusted adults and make them aware of the content of the unit. The letter also provides an opportunity for trusted adults to share important context with you about students' experiences and background that might be relevant.

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

Often in science classrooms, we are focused on evidence and data. When addressing a phenomenon or design solution that straddles the nature-cultural divide, like this one, supporting students in using a social and emotional lens will also be important. Make space for students to process and validate their feelings and reactions. These opportunities were built in throughout the unit. *Feelings Wheel* is one tool students are provided for processing feelings and reactions.

The impact of climate change is a prominent theme in this unit. Youth feel sadness, fear, and anxiety about climate change (Hickman et al., 2021), and for students who have previously experienced trauma, this can have a compounding effect (Effects of complex trauma, NCTSN). Gislason & Kennedy (2022) suggest that offering 'grounded hope' in science education that transparently and accurately communicates the facts of climate change while seeking to develop confidence and self-efficacy in the ability of individuals to impact outcomes can counter feelings of hopelessness and anxiety that can occur when discussing climate change.

Consistent with the goals of trauma-informed social and emotional learning such as transparency, agency, empowerment, and strengthening emotion regulation, throughout this unit, we provide multiple opportunities to cultivate student confidence in their ability to positively impact their climate at a local level:

- **Little hero moments:** We provide local examples of people in communities taking action to address climate issues. These actions are accessible to high school students, modeling for them potential actions they could also take in their communities, such as:
 - Lesson 2- students consider the ethics of gathering and burning fuel samples while being responsible.
 - Lesson 7- students ask hopeful questions and share ideas for what could be done to prevent or reduce the intensity and frequency of future fires.
- **Brainstorming solutions:** We encourage students to extrapolate from information presented to consider solutions that could work in their local community and context.
- **Hope-focused lessons:** The examples of fire management solutions described in Lesson 10 and community fire management systems created in Lesson 11 provide examples of actionable ideas that can be used to protect nonhuman populations from the effects of fragmentation in any community.

We focus students on considering local, context-specific actions that are accessible and personal (Christensen et al., 2023) with the goal of ensuring students accurately understand our climate context and feel empowered to impact and improve their local community

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

This unit is informed by the Learning in Places complex socio-ecological systems framework. This framework involves sensemaking across five dimensions (species, kinds & behaviors; relationships; places, lands & waters, thinking across scales, and ethical deliberation and decision-making) under an umbrella of power and historicity. These dimensions include making sense of both human and other-than-human values, needs, and behaviors across multiple temporal and spatial scales. The framework guides learners towards designing actions or making decisions for making change in adaptive and resilient ways. Students use these dimensions to figure out how and why different ecosystems are more impacted by fire and to evaluate fire management case studies. This allows them to raise questions about how carbon sinks became more likely to burn, who is and is not involved in decision-making (historically and currently), and what impacts those decisions have on humans and other-than-humans. It also facilitates thinking about these ecosystems at multiple scales over long periods of time.

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

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

Guidance for Developing Your Personal Glossaries

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

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

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

Lesson	Definitions we co-construct	Definitions we encounter
L1	zombie fire	burn scar, socio-ecological systems, components*, interactions*, matter**, energy**, systems, scale
L2	fuel, peat, energy**, matter**	permafrost
L3	carbon sink	cellular respiration**, aerobic, anaerobic
L4	photosynthesis**	tilt
L5	chemical energy	directional hypothesis
L6	zombie fire (revise)	
L7		fire suppression, biosphere**, atmosphere**
L8	climate change, greenhouse gasses	
L9	feedback effects, carbon cycle	geosphere**, hydrosphere**
L10		biomass*, food web**
L11	trade-offs	criteria*, constraints*, interest holder*
L12		dissolved oxygen (revisit)

*Co-constructed or encountered in a previous OpenSciEd High School unit.

**Co-constructed or encountered in the middle school grade band of NGSS/OpenSciEd Middle School.

HOME COMMUNICATION

Dear Parents, Guardians, and Caregivers:

Your child's high school biology class is starting a unit called, *What causes fires in ecosystems to burn and how should we manage them?* as part of the OpenSciEd high school science curriculum. This unit develops science ideas around energy and matter cycling in ecosystems (and at the global scale). Here are some resources with additional background knowledge:

- Zombie fires more frequent in boreal forests: <https://theconversation.com/zombie-fires-are-occurring-more-frequently-in-boreal-forests-but-their-impacts-remain-uncertain-198459>
- Video: News report on increased zombie fires: <https://www.youtube.com/watch?v=qF99NMwPCOM>
- NOAA History of Atmospheric Carbon Dioxide: <https://gml.noaa.gov/ccgg/trends/history.html>
- Karuk Fire Management (California): <https://vimeo.com/458221338>
- PBS The Age of Nature, Episode 3: <https://wisconsin.pbslearningmedia.org/resource/full-program/the-age-of-nature-video-gallery/>

Students draw on their personal experiences with fire to make predictions about a new phenomenon related to how fire could burn under ice and release massive amounts of carbon dioxide. Students may come home with questions about how fires happen and what could cause fires to burn for long periods of time. If your student has experienced a residential fire or wildfire, please encourage them to talk with a trusted adult about their thoughts and experiences as they progress through this unit. We encourage you to share your experiences, ideas, and questions as well.

Your student will be conducting experiments using fire in class. **IMPORTANT:** YOUR STUDENT DOES NOT NEED TO CREATE ANY FIRES AT HOME.

Helping your student make sense of their learning:

- There is no need to teach your child vocabulary before the unit because the class will co-construct the meanings of words necessary to figure out what is happening with the phenomena.
- Encourage your child to expand and clarify their own thinking by asking for examples, saying more about their ideas, and repeating what they said back to them.
 - That's really interesting. You just said... Tell me more about that.
 - When you said X, I started wondering about Y. What do you think?
- Ask how they might have arrived at a particular conclusion.
- Ask your child to recall what other students have said in class and what about the other students' ideas they agreed or disagreed with.
- Rephrase or paraphrase what your child says as a way to clarify their ideas.

Having conversations about science:

- Encourage your child's curiosity through talking about their own noticings and wonderings.
- Share what you wonder about too and ask what they think.
- Ask your child to explain how other fires could be helpful or harmful.
- Have honest conversations with your student about balancing the risks and benefits of fire.

Estimados padres, tutores y cuidadores:

La clase de biología de la escuela secundaria de su hijo está comenzando una unidad llamada *¿Qué causa que ardan los incendios en los ecosistemas y cómo debemos manejarlos?* como parte del plan de estudios de ciencias de la escuela secundaria OpenSciEd. Esta unidad desarrolla ideas científicas sobre el ciclo de la energía y la materia en los ecosistemas (y a escala global). Aquí hay algunos recursos con conocimientos previos adicionales:

- Incendios zombies son más frecuentes en bosques boreales: *Unknown material with identifier: op.bo.vid.l1.100*
- Video: Informe de noticias sobre el aumento de incendios de zombies: *Unknown material with identifier: op.bo.vid.l1.103*
- Historia de la NOAA sobre el dióxido de carbono atmosférico: <https://gml.noaa.gov/ccgg/trends/history.html>
- Manejo de incendios de Karuk (California): <https://vimeo.com/458221338>
- PBS La era de la naturaleza, episodio 3: <https://wisconsin.pbslearningmedia.org/resource/full-program/the-age-of-nature-video-gallery/>

Los estudiantes se basan en sus experiencias personales con el fuego para hacer predicciones sobre un nuevo fenómeno relacionado con cómo el fuego podría arder bajo el hielo y liberar cantidades masivas de dióxido de carbono. Los estudiantes pueden regresar a casa con preguntas sobre cómo ocurren los incendios y qué podría causar que los incendios ardan durante largos períodos de tiempo. Si su estudiante ha experimentado un incendio residencial o un incendio forestal, animelo a hablar con un adulto de confianza sobre sus pensamientos y experiencias a medida que avanza en esta unidad. Le animamos a compartir sus experiencias, ideas y preguntas también.

Su estudiante realizará experimentos usando fuego en clase. **IMPORTANTE:** SU ESTUDIANTE NO NECESITA CREAR NINGÚN FUEGO EN CASA.

Ayudar a su estudiante a darle sentido a su aprendizaje:

- No es necesario enseñarle vocabulario a su hijo antes de la unidad porque la clase co-construirá los significados de las palabras necesarias para descubrir qué está sucediendo con los fenómenos.
- Anime a su hijo a ampliar y aclarar su propio pensamiento pidiéndole ejemplos, diciendo más sobre sus ideas y repitiéndole lo que le dijo.
 - Eso es realmente interesante. Acabas de decir... Cuéntame más sobre eso.
 - Cuando dijiste X, comencé a preguntarme sobre Y. ¿Qué piensas?
- Pregúnteles cómo pudieron haber llegado a una conclusión particular.
- Pídale a su hijo que recuerde lo que otros estudiantes han dicho en clase y qué hay de las ideas de los otros estudiantes con las que estuvieron de acuerdo o en desacuerdo.
- Reformule o parafrasee lo que dice su hijo como una forma de aclarar sus ideas.

Tener conversaciones sobre ciencia:

- Fomente la curiosidad de su hijo hablándole sobre sus propias observaciones y dudas.
- Comparte también lo que te preguntas y pregúntales qué piensan.
- Pídale a su hijo que le explique cómo otros incendios podrían ser útiles o dañinos.
- Tenga conversaciones honestas con su estudiante sobre cómo equilibrar los riesgos y beneficios del incendio.

LESSON 1: How can fires burn under ice and release so much energy and matter?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

3 days



Bureau of Land Management, Alaska Fire Service

We do a visual inquiry to investigate zombie fires. We share our experiences and ideas about how our lives are connected to fires. We develop initial models to explain the interactions in the zombie fire system and how they release so much carbon. We develop a DQB and decide to investigate how zombie fires could be burning under the ice.

NEXT LESSON *We will investigate what is burning in zombie fires. We will observe peat and other fuels, read about peat, and burn peat and other fuels for fire.*

BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



WHAT STUDENTS WILL DO

1.A Obtain information about zombie fires to identify potential **cause and effect relationships** that lead to **changes in the biosphere and atmosphere**. (SEP: 8.1; DCI: ESS2.D.3; CCC: 2.2)

1.B Develop a model to explain how **matter (peat)** and **energy (fire)** flow in the zombie fire system. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)

1.C Ask questions to clarify how the **flow of energy and matter in the atmosphere (CO₂/smoke)** and **biosphere(peat/permafrost)**, allows zombie fires to burn, **including the role of humans**. (SEP: 1.4; DCI: ESS2.D.3; CCC: 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Zombie fires burn under ice throughout the winter.
- In zombie fires, peat is burning in the thawing permafrost.
- Matter and energy are flowing from the peat/permafrost to the air as smoke and carbon dioxide.
- Zombie fires are not very common but are becoming more common.

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	10 min		NAVIGATE Introduce a new phenomenon and elicit initial questions.	A-D	<i>Arctic Fires</i> , chart paper, chart paper markers
2	10 min		REVISIT COMMUNITY AGREEMENTS AND PREPARE FOR VISUAL INQUIRY Revisit established Community Agreements from earlier units and set up notebooks for visual inquiry.	E-G	<i>Arctic Fire Noticings/Wonderings</i> , <i>Feelings Wheel</i> , Community Agreements poster from previous unit, <i>Example Community Agreements</i> (optional)
3	15 min		VISUAL INQUIRY: ZOMBIE FIRES Investigate images and text from the Zombie Fire Visual Inquiry.	H	<i>Arctic Fire Noticings/Wonderings</i> , https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing
4	8 min		INITIAL IDEAS DISCUSSION Facilitate an Initial Ideas Discussion about the components and interactions students notice in the <i>Arctic Fire Visual Inquiry</i> .	I-J	<i>Arctic Fire Noticings/Wonderings</i> , https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing
5	2 min		NAVIGATE: HOME LEARNING Share a home learning opportunity with students.	K	<i>Fire Connections Home Learning</i> , <i>Fire Stories</i> (optional)
End of day 1					
6	5 min		NAVIGATE Ask students to share their home learning with the class.	L	<i>Fire Connections Home Learning</i>
7	7 min		BRAINSTORM RELATED PHENOMENA Support students in connecting to phenomena beyond zombie fires.	M	chart paper, chart paper markers
8	11 min		DEVELOP INITIAL MODELS Develop initial individual models to explain how fire can burn under ice.	N-P	3 x 3 sticky notes
9	4 min		REVISE INDIVIDUAL INITIAL MODELS Return to individual initial models after sharing in small groups to revise or add any new ideas.	Q	
10	13 min		DEVELOP INITIAL CONSENSUS MODEL Facilitate an Initial Consensus Discussion about similarities and differences between the individual zombie fire models.	R	chart paper, chart paper markers
11	5 min		NAVIGATE Use ideas from the consensus model to develop questions we can investigate.	S	
End of day 2					

Part	Duration		Summary	Slide	Materials
12	5 min		NAVIGATE Guide students in writing DQB questions.	T	
13	18 min		BUILD THE DRIVING QUESTION BOARD Form a Scientists Circle to create a Driving Question Board.	U	3x3 sticky notes, chart paper markers, chart paper
14	10 min		CONSIDER IDEAS FOR INVESTIGATION Help students generate and share specific investigative ideas for addressing questions about the mechanisms allowing zombie fires to burn under ice.	V	chart paper, chart paper markers
15	7 min		INTRODUCE AND UPDATE PROGRESS TRACKERS Introduce the Progress Tracker and have students complete it.	W	<i>Fires Progress Tracker</i>
16	5 min		NAVIGATE Facilitate students brainstorming what question to investigate first.	X	chart paper, chart paper markers

End of day 3

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Arctic Fires</i> <i>Arctic Fire Noticings/Wonderings</i> <i>Feelings Wheel</i> <i>Fire Connections Home Learning</i> <i>Fire Stories</i> (optional) 3x3 sticky notes - chart paper markers <i>Fires Progress Tracker</i>	https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtK5gfc/edit?usp=sharing	- chart paper - chart paper markers - Community Agreements poster from previous unit <i>Example Community Agreements</i> (optional) 3 x 3 sticky notes

Materials preparation (20 minutes)

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

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

Before the unit begins, send home *Fires Home Communication* with students to alert families to the unit content around wildfire.

Review the unit overview to see how disciplinary core ideas, crosscutting concepts, and science and engineering practices are developed in this unit.

Make sure the class Community Agreements poster (created in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*) is hung where students can see it. If you are teaching this unit without having developed these agreements, spend at least 15 minutes developing them as described in *Serengeti Unit*. This scaffold is not referenced explicitly here because this unit is the second unit in the Biology course, but it should be available for reference in case students encounter interpersonal conflict or need to be reminded of an agreement that is not being followed.

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

Day 1:

- Gather devices (tablets, chromebooks, etc.) so that each group can access the visual inquiry slides, in groups of 3–4 students. A non-screen alternative is available for students to access the visual inquiry by printing the slides.
- Gather chart paper and chart paper markers or equivalent.

Day 2:

- Gather 3x3 sticky notes and colored markers for questions.
- Gather chart paper and chart paper markers or equivalent to create the Initial Class Consensus Model.

Day 3:

- Gather chart paper, 3x3 sticky notes, and colored markers for the Driving Question Board and Ideas for Investigations posters.

While you will create many posters throughout the unit, it is helpful to keep the Driving Question Board, Initial Consensus Model, Related Phenomenon, and Ideas for Investigations and Data We Need posters easily accessible as you move through the unit to not only keep track of progress on science ideas but also to continually engage students with relevance.

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

This lesson builds a foundation for the rest of the unit using prior grade band ideas related to energy and matter. Students will formally revisit, investigate, and collect evidence for tracking energy and matter flows into, out of, and within systems to help explain the system's behavior, beginning in Lesson 2. Because this is the first lesson in a new unit, the goal is not to establish any ideas associated with the relevant DCIs, but rather to elicit student ideas related to that DCI. The DCI elements that students will be thinking about in this lesson include:

- LS1.C.3: As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.
- ESS3.D.3: Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate:

Students use elements of the science practices of *asking questions and defining problems*, *developing and using models*, and *obtaining, evaluating and communicating information* to make initial sense of what happens in the zombie fire system as permafrost thaws and peat burns.

Students use elements of the crosscutting concepts *cause and effect*, *systems and system models*, and *energy and matter* as they begin to interact with the unit phenomenon.

In this lesson, students will co-construct a definition for: *zombie fire*. They will encounter the terms *burn scar* and *socio-ecological systems*. In addition, students will encounter several terms that are included in previous grade bands in the NGSS performance expectations in this lesson. These include: *components*, *interactions*, *matter*, *energy*, *systems*, and *scale*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

The terms *climate change* and *global warming* will likely be used throughout this lesson by students. At this point in the unit, it is not important for students to have a complete understanding of ideas. Students will develop their understanding of climate change across the unit and in OpenSciEd Chemistry and Physics..

Where We Are NOT Going

Students will engage with their communities outside of the classroom to bring some relevant cultural experiences to the classroom that may support the class with figuring out the phenomenon. We will not investigate all of the fires from around the world that students and their communities have experience with and might be interested in. Students will investigate fires related to other carbon sinks/locations and more local connections to fires in Lesson Sets 2 and 3.

LEARNING PLAN for LESSON 1

1 · NAVIGATE

10 min

MATERIALS: science notebook, *Arctic Fires*, chart paper, chart paper markers

ADDITIONAL GUIDANCE

Before the start of the unit, consider letting students know that the class will be discussing fires to give them time to process and raise any questions they have. Be mindful that sharing or hearing stories of past fires can bring up past or recurring trauma for students. However, not all students will associate the class content with trauma, and it is important not to make assumptions about students' emotional states.

It is advisable to send home communication to families, letting them know the subject of the unit in advance so they can inform you of any topics that may be sensitive for students. The *Fires Home Communication* can be edited for your context.

You may want to ask students to think about a trusted adult who they can talk to about difficult topics. This should be done privately (e.g., on an exit slip or electronically). If students are not able to identify a trusted adult, consider offering to fill that role for them or contact a support person in your school who can help.

If possible, we also recommend seeking the assistance of a school psychologist, social worker, mental health specialist, or counselor to support discussions that may be challenging for some students. They may also be able to help you identify students you should check in with before the unit. Please see additional guidance on SEL and justice-oriented teaching in the *Teacher Background Knowledge* and the *OpenSciEd Teacher Handbook: High School Science*.

ADDITIONAL GUIDANCE

Please be aware that while often used in pop culture and here as the name of a scientific phenomenon, the word *zombie* has complicated origins. Amy Wilentz of the New York Times wrote about a zombie being more than the often-portrayed walking dead, "He (a zombie) is a New World phenomenon that arose from the mixture of old African religious beliefs and the pain of slavery, especially the notoriously merciless and coldblooded slavery of French-run, pre-independence Haiti. In Africa, a dying person's soul might be stolen and stopped up in a ritual bottle for later use. But the full-blown zombie was a very logical offspring of New World slavery."

For more information, see the following resources:

- https://www.nytimes.com/2012/10/31/opinion/a-zombie-is-a-slave-forever.html?smid=fb-share&_r=1&
- <https://www.theatlantic.com/entertainment/archive/2015/10/how-america-erased-the-tragic-history-of-the-zombie/412264/>
- <https://www.npr.org/sections/codeswitch/2013/12/13/250844800/zoinks-tracing-the-history-of-zombie-from-haiti-to-the-cdc>

If you feel uncomfortable using the word *zombie*, an alternative would be to call the zombie fires Arctic fires, holdover fires, or overwintering fires.

For more information on zombie fires, see the resources in *Teacher Background Knowledge*.

* ATTENDING TO EQUITY

Building classroom culture and norms:

Community-building is emphasized throughout this unit. In this lesson, it is important to encourage students to draw from their own ideas and not to worry about whether their ideas or questions are right or wrong. At this stage in an investigation, there are no correct ideas or questions. All ideas and questions are welcome and valuable.

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Initial questions about a phenomenon are intended to clarify what information is known and not known and, as is often the case, there are more questions than answers when scientists begin their investigations. Develop a safe and supportive space for students' uncertainty and focus on the need to ask and answer questions to help address and resolve their uncertainty over the course of the unit.

Navigate and introduce the zombie fire phenomenon. Display **slide A**. Say, *NASA scientists were flying over areas near the Arctic Circle and noticed something interesting. In areas where there had been wildfires the previous fall, new fires were burning very close to where the old fires had been. When scientists look at land that was previously burned and damaged by a forest fire, they call what is left over a burn scar. This image shows two burn scars from fall 2015 and an active wildfire in spring 2016.* Ask students to notice and wonder out loud with the class about the burn scar image.

Get acquainted with the Arctic. Display **slide B**. Support students in understanding where the Arctic is located and the countries that are in this region to build context for how unusual this phenomenon is.

Read about Arctic Fires. Display **slide C**. Acknowledge student noticings and wonderings and then distribute *Arctic Fires*. Have students read and annotate using whatever strategy is in place in your school/classroom. Remind students that they can use their Personal Glossaries to record definitions they encounter that they would like to keep track of, such as *burn scar*.

Stop and Jot initial questions before sharing as a class. Display **slide D**. Have students record any questions in their science notebooks. Students will revisit these questions through the lesson as they do a visual inquiry and later build the Driving Question Board. * *

Suggested prompt	Sample student response
<i>What do we want to know about this fire and the system it was a part of? What initial questions do you have?</i>	How can there be forest fires in the Arctic where it is really cold and snowy? What is burning in these fires? How do the fires start? How big are these fires? Is there snow where these fires happen? What is the temperature where these fires are happening? How long did the fires burn? Are there people who live near these fires? What else do these fires affect? What are all the different parts/components in this system needed for zombie fires to happen?

After hearing a variety of student questions, say, *It seems like we want to know even more about the components and interactions in these zombie fire systems. Let's take some time to investigate our questions.*

SCIENCE NOTEBOOK



If your students have not set up their notebooks yet, ask them to set up a section of their binders for the current unit where they will keep all of their handouts and notes for the unit organized. They should have dividers to keep materials from each unit separate and loose-leaf paper to use throughout the unit. The handouts you provide to students should be three-hole-punched and placed in the section of their binders designated for the unit. If they have not already established a section in their notebooks for their Personal Glossaries, take a moment to have them set it up so they will be ready to add important scientific terminology as the unit progresses.

2 · REVISIT COMMUNITY AGREEMENTS AND PREPARE FOR VISUAL INQUIRY

10 min

MATERIALS: science notebook, *Arctic Fire Noticings/Wonderings*, *Feelings Wheel*, Community Agreements poster from previous unit, *Example Community Agreements* (optional)

Prepare for a visual inquiry. Display **slide E**. Distribute *Arctic Fire Noticings/Wonderings*.

ADDITIONAL GUIDANCE

If this is the students' first Notice and Wonder chart, model for students a *notice* or observation and a *wonder* or question. Demonstrating an example will help students focus their noticings and wonderings on the phenomenon and not on distracting details. One way to model this is to use an example from earlier in the lesson such as the burn scar or other initial fire images to share initial noticings and wonderings. Ask two or three students to share one thing they noticed and/or wondered about and write that on the board as an example. Ask students if they have any questions about what to record on each side of the chart.

Pause for a SEL moment. Display **slide F**. Say, *We are going to examine images and data from real fires. These fires are complex and involve human and nonhuman parts of ecosystems. We need to respect everyone's lived experiences around fire. All social and ecological systems interact in a complex web of relations across time and place. These are referred to as socio-ecological systems. We will use a set of slides organized around 5 different dimensions (as the headings) to help us obtain information about zombie fires. As we do this, you may have a variety of feelings that you experience. Here is a tool to help you name or identify those feelings.* Hand out the *Feelings Wheel* at this time as a reference for students to use to identify their feelings throughout the unit. Remind students that all feelings are valid.

Revisit and add to our Community Agreements. Display **slide G**. Say, *Before we dive into looking at images and data from these interesting zombie fires, let's take a look at the classroom Community Agreements we established earlier in the school year.* Ask students to think about which of the Community Agreements we might want to focus on as we discuss a potentially emotionally sensitive topic like fire. Students may share ideas about how focusing on the *respectful* and *committed to our community* might help us when discussing difficult topics. Ask students to suggest specific ways they might draw on these Community Agreements to support difficult conversations. Let students know that when the class discusses topics that feel emotionally challenging, they should feel comfortable asking to step out of the room. *

Choose a Community Agreement to work on today. Ask students to read through the Community Agreements one more time, nominate one agreement that may be particularly hard to follow and suggest a strategy that could help everyone adhere to it. Then, before the students end their conversation, give students 30 seconds to silently pick one agreement from the slide that they personally will work on today. *

* ATTENDING TO EQUITY

Universal Design for Learning: It is important to use this Community Agreement-building to revisit how to cultivate an equitable learning community that promotes trusting and caring relationships that foster student *engagement*. The Community Agreements should remind students to value the diversity of classroom community members and equity in the sensemaking work they will do together this school year. It is critical that the Community Agreements support safe and fair participation and interrupt stereotypes that could make science experiences feel uncomfortable to students.

* ATTENDING TO EQUITY

One of the reasons that OpenSciEd uses the term *Community Agreements* is to highlight that there are many ways to collaborate. Community Agreements are a powerful tool for equity in the classroom when made collaboratively and thoughtfully. But be aware that ideas such as *safe*, *respectful*, *polite*, *nice*, and *kind* are culturally embedded and can mean different things in different communities. For example, one student may define kindness as not calling out a peer in public when they say something offensive. But another student may define kindness as being honest with peers and sharing what is on their mind and heart right away. Whose version of kindness receives priority? When these ideas are not explored, Community

ADDITIONAL GUIDANCE

The slides <https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing> are organized around the 5 dimensions of complex socio-ecological systems. Students will see the 5 dimensions in the slide headings. Students will further explore this framework as they revise their thinking around the impact of fire on socio-ecological systems throughout the unit. This framework was adapted from: *Learning in Places Collaborative (2022). Framework: Complex Socio-Ecological Systems*. Bothell, Seattle, WA & Evanston, IL: Learning in Places. Please see <http://learninginplaces.org/frameworks/complex-socio-ecological-systems-framework/> for further information and guidance.

Agreements can be used to police or silence justifiable hurt and anger, particularly when it comes from students who identify with marginalized communities. For some examples of inclusive Community Agreements that support equitable spaces, visit <https://www.theequitylab.org/blog/why-start-with-agreements> or *Example Community Agreements*.

3 · VISUAL INQUIRY: ZOMBIE FIRES

15 min

MATERIALS: science notebook, *Arctic Fire Noticings/Wonderings*, <https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing>



Conduct a visual inquiry of the zombie fires. Display slide H. ** Divide students into groups of 3-4. For each group, provide a device with access to the *Arctic Fire Visual Inquiry* <https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing>. Allow students to work together to obtain information from the slides dedicated to each dimension. Assign each group to start with a different dimension. Give groups 3 minutes to examine the *Arctic Fire Visual Inquiry* for each dimension and communicate in writing their notices and wonders on *Arctic Fire Noticings/Wonderings*. Tell groups that they will go through each of the 5 dimensions and then have 3 minutes to revisit any dimensions where they need more time.

ADDITIONAL GUIDANCE

The <https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing> is available as both digital slides and can be printed. The recommendation is to print one-sided color copies and place a copy of each of the slides on a table for each group. Alternatively, if you have a small class, you could place the slides for each dimension on the table and have groups move around to each dimension in a station activity. If students access the slides digitally, make sure to have one device for every 3-4 students placed around the room so that there is no crowding and each student can access the scientific text and images.

* ATTENDING TO EQUITY

Supporting Emergent Multilinguals:

Depending on the goals of a lesson, or the goals for a particular aspect of a lesson (in this case, to obtain and communicate information), it is helpful to intentionally group emerging multilingual students with certain peers. Sometimes this could be peers who know the same languages as they do, while other times it could be peers whose English language development is slightly more advanced. It is important that this grouping be thoughtful and that it varies throughout the course of a unit so that students benefit from working with different peers.

* ATTENDING TO EQUITY

Supporting students with visual images:

This unit uses images as data. In this lesson, students obtain information from color images of places, lands, and different species. You will need to make accommodations so that students who are color blind or have other visual differences can access this data. Depending on your students' needs, suggested modifications include enlarging and/or brightening the provided digital versions of these photos or using alternate text descriptions.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Collect *Arctic Fire Noticings/Wonderings* to look for the scientific and technical information obtained and communicated in writing (SEP: 8.1):

- A **zombie fire** is when a fire burns **peat in/under the ice** near the Arctic Circle (where it is very cold) during the spring very close to where a previous **fire burned the fall before**. (DCI: ESS2.D.3; CCC: 2.2)
- Zombie fires happen more (**effect**) when the temperatures of the Arctic are **warmer during the summer months** (**cause**). (DCI: ESS2.D.3; CCC: 2.2)
- Zombie fires are **causing** a lot of carbon dioxide to be released into the air/**atmosphere**. (DCI: ESS2.D.3; CCC: 2.2)
- A zombie fire is a recently discovered phenomenon that involves **living/once living things** (biosphere), **ice/snow** (cryosphere), and the **atmosphere**. (DCI: ESS2.D.3)
- **Smoke containing carbon dioxide** travels very far from the fires (**a smaller system**) to big cities (**a larger system**), **causing** the air to be bad for breathing (**effect**). (CCC: 2.2; DCI: ESS2.D.3)
- Zombie and forest **fires** are **destroying a lot of habitat/ecosystems**. (CCC: 2.2; DCI: ESS2.D.3)

What to do: Circulate around the room as students work and point them back to the *Zombie Fire Visual Inquiry* if you notice that they are not connecting the increase in carbon dioxide in the atmosphere to fires in the Arctic. Ask questions such as:

- What do you think could cause the increase in atmospheric carbon dioxide?
- What are the impacts or effects of the zombie fires?

Collect *Arctic Fire Noticings/Wonderings* after the Initial Ideas Discussion in the next activity and use *Arctic Fire Noticings/Wonderings Key* for additional guidance to provide individual feedback to students. If student responses do not resemble the responses on the key, provide additional time for them to work with the *Zombie Fire Visual Inquiry*. Consider grouping students who struggled with a certain dimension with students who demonstrated a higher level of understanding.

Building toward 1.A Obtain information about zombie fires to identify potential **cause and effect relationships** that lead to **changes in the biosphere and atmosphere**. (SEP: 8.1; DCI: ESS2.D.3; CCC: 2.2)

Do not collect *Arctic Fire Noticings/Wonderings* at this time so students may use it to scaffold their ideas in the following discussion. You may choose to collect *Arctic Fire Noticings/Wonderings* at the end of the day to provide feedback to students before they develop their initial models on the second day of the lesson.

4 · INITIAL IDEAS DISCUSSION

8 min

MATERIALS: science notebook, *Arctic Fire Noticings/Wonderings*, <https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing>

Share what we notice and wonder about zombie fires. Display slide I. Have students turn and talk with an elbow partner who was not in their small group.

Facilitate an Initial Ideas Discussion about what we notice and wonder about the zombie fires. ✱ Call on a few student pairs and ask them to share their ideas. Record these ideas on the whiteboard. Encourage students to build on each others' ideas using prompts such as, *Did any pair discuss similar ideas?* or *Who can build on this idea?*

✱ STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

Reasons for eliciting students' initial ideas include:

- To get students' prior knowledge and experiences on the table.
- To provide a supportive opportunity for students to make sense of what may not be fully formed ideas (either their own ideas or those of others).

KEY IDEAS

Purpose of this discussion: To elicit student ideas related to zombie fires and make it possible for the unit to build on those ideas.

Listen for these ideas:

- It is very cold, and zombie fires are still burning.
- Zombie fires burn underground throughout the winter.
- Zombie fires are often started by forest fires.
- There are people living where these zombie fires occur.
- There are lots of different animals and plants in the zombie fire ecosystem.
- The smoke from zombie fires travels long distances.

Pay attention to students who may be experiencing trauma and connect them with additional resources and support as available.

- To help students realize that there are gaps in our understanding in order to promote curiosity and consider what we could do next to figure something out.

Suggested prompt

Sample student response

What do you know about zombie fires?

Zombie fires burn under the ice.
Zombie fires happen near the Arctic Circle.
Zombie fires can burn during the winter under the ice and emerge in the spring.
The fires burned for a long time over a big area.
Animals lost their homes.
Rising temperatures are making it worse.
Zombie fires keep burning over winter.
Permafrost is thawing.
There is lots of carbon dioxide coming out, and it can affect places beyond the Arctic.

How have your experiences helped you connect to zombie fires?

Fires also happen where I live.
The Earth is changing where I live as well.
The air quality has been bad where I live even though I live far away from fires.

What do you not know about zombie fires that you want to understand better?

I want to know how the fires can burn under the ice all winter.
I want to know what peat is.
I want to know how the fires release so much carbon and where that carbon comes from.

Revise responses in *Arctic Fire Noticings/Wonderings*. Give students time to revise their ideas in their Notice and Wonder charts and collect student work.

Update Personal Glossaries. Display slide J. Say, *Are there any new words or concepts we have built that need to be added to our Personal Glossaries?* Students will likely identify *zombie fires*. Explain to the students that we do not know a lot about zombie fires yet, so our definition may not be exact, but it can be revised over time. Give students a minute to add this term to their Personal Glossaries, as well as any others they wish to add. Encourage students to include drawings or images that might be helpful as they build their understanding of this term.

ADDITIONAL GUIDANCE

Students' entries may look like this: *Zombie fires are when forest fires from the fall go down into the ground over winter and continue to burn, coming above ground in the spring.* Students may or may not mention peat burning or permafrost thawing in their definitions.

At this point, students will have encountered a number of definitions such as *burn scar* and *socio-ecological systems*. Encourage them to add these and any other definitions that they think would be helpful to their Personal Glossaries.

ADDITIONAL GUIDANCE

Throughout the course of our work together, we will learn a lot of new vocabulary. A *definition we co-construct* is one we work together to understand through investigation and collaborative sensemaking, thus we should celebrate our growing understanding of the word by adding it to our Personal Glossaries. A *definition we encounter* in text or media is defined for us. Students can add any other definitions they find useful to their Personal Glossaries as they are encountered.

5 • NAVIGATE: HOME LEARNING

2 min

MATERIALS: *Fire Connections Home Learning*, *Fire Stories* (optional)



Introduce Home Learning. Say, *We have already figured out a lot about fires in the Arctic. Many of us do not have personal experience with the Arctic, but have personal experiences with fire in other systems that can help us make sense of the zombie fire system. Ask, What could we do to gather even more stories about fires or related phenomena?* Listen for students to suggest asking friends and family.

Say, *I bet there is a lot we can learn from your stories and the stories of those in your families and communities. Let's gather some of these stories for next time.*

Assign the home learning on slide K. In addition to recording their own experiences, students should ask at least one person from their family or community if they have ever been impacted by wildfires or other fires, and if so, ask them the questions on *Fire Connections Home Learning*. If students identified a trusted adult earlier in the lesson, encourage them to connect with that person as they engage with the home learning. Tell students, *Keep track of your interviewees' ideas on the handout or on a piece of paper in your notebook so that you can share them with your classmates the next time we are together. If you have an experience you feel comfortable sharing, please write your responses down as well.*

HOME LEARNING OPPORTUNITY



Home learning is an important place to engage in cultural formative assessment (Penuel, Shepard, & Davidson, 2016), where students bring ideas generated in their home communities into school and vice versa. By encouraging students to gather ideas from their communities, you are blurring the boundaries of home and school learning and making for a more meaningful and integrated science experience.

ADDITIONAL GUIDANCE

For students in some geographic locations, the Arctic fire phenomenon may feel distant and abstract. Ask those students to think about the second question on **slide J** (or *Fire Connections Home Learning*) about direct or indirect impact from fires like the Arctic or other fires. This can help all students feel a sense of belonging by positioning them and their broader communities as sources of scientific knowledge. Ask about specific indirect impacts they or their community might have faced, such as air quality, climate/weather changes, loss of home/habitat, or access to resources.

While students may not feel geographically connected to the Arctic, there are peat fires happening in many regions all over the Earth. Additionally, this is a chance to highlight other knowledge systems, cultural connections to fire, and connections to changes in places, lands, and waters. For examples of recent fire stories shared by students, please see *Fire Stories*. In addition, if your students have trouble connecting with fires impacting their communities you could use *Fire Stories* to share stories from other high school students.

ALTERNATE ACTIVITY

Consider creating a digital space, like a post in Google Classroom or a Flipgrid link, where students can share the fire stories from others on day 2. If most or all students know someone with an experience to share, this is also a great opportunity to collaborate with an English Language Arts teacher for students to create expository texts using Common Core standards such as CCSS.ELA-LITERACY.W.9-10.2 or CCSS.ELA-LITERACY.W.9-10.3.

End of day 1

6 • NAVIGATE

5 min

MATERIALS: *Fire Connections Home Learning*

Share your home learning with a neighbor. Display **slide L**. Have students talk to an elbow partner before sharing a few connections with the class. As they discuss the question on the slide, ask *What did you discover by asking questions of your family, friends, and neighbors?* Listen for ideas such as:

- I visited _____, and there were fires happening there.
- My aunt in California always says their fires are drought-related.
- There are fires in the city I live in, but they are not necessarily wild/forest fires.
- I have asthma, and when there is more smoke, it is harder to breathe.
- We are seeing more fires near our community than we used to.
- We can see smoke from wildfires near where I live even though the fires are far away.

7 • BRAINSTORM RELATED PHENOMENA

7 min

MATERIALS: science notebook, chart paper, chart paper markers

Turn and talk about related phenomena. Display **slide M**. Direct students to talk with a neighbor about the questions on the slide. * Then after two minutes, discuss as a class and record the answers on chart paper. * Listen for examples such as:

- There are wildfires burning near where people I know live.
- Are there some plants/trees that are fire-resistant?
- I heard of other fires burning in _____
- It is getting hotter in _____ and fires are burning more there.
- Fires last summer made lots of smoke where we live.

Say, *These are all great connections and questions! Before we make a plan to figure out how to answer them, let's see if we can develop a model of what we already know about zombie fires and then the areas of the model where we have questions.*

If you have collected but have not yet handed back *Arctic Fire Noticings/Wonderings*, do so now so students may use their noticings and wonderings, plus your feedback, to develop their initial models in the following step.

ADDITIONAL GUIDANCE

Keep the related phenomena poster you create accessible to students throughout the unit. You will formally revisit in Lessons 6, 9, 10, and 11, but it can be a helpful tool at any point in the unit to remind students of their connections, motivate figuring out new ideas, and increase relevance and engagement for students.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Since models are used to explain a range of phenomena, students will refer back to this list of related phenomena throughout the unit to help them generalize the model(s) they develop and predict interactions in other systems. As students suggest ideas, press them to explain how they are related. This will help students expand their thinking beyond the individual components to the interactions and mechanisms that will be explained by their models.

* ATTENDING TO EQUITY

Use talk strategies to draw out a wide variety of related phenomena from a larger pool of students. Have students jot down some ideas in their notebooks after their partner talks and before sharing. This can be particularly supportive for emergent multilingual students.

Use questions to push students' thinking to new contexts and provide more opportunities for students to make connections to their experiences. For example, if students are only connecting to the Arctic or fires with ice, remind them that the zombie fires started as forest fires and ask them if they have any connections to fires that might be closer to their community.

If it seems like the students do not have any more ideas, resist moving on right away. Instead, count to 10 in your head to give students more time to consider.

8 • DEVELOP INITIAL MODELS

11 min

MATERIALS: science notebook, 3 x 3 sticky notes



Develop initial models. Display **slide N** and say, *Energy and matter is a crosscutting concept you have probably used to make sense of a lot of phenomena you have encountered in science class and beyond. I think it can help us here!* Let students know that they will have an opportunity to think about this as they develop initial models that illustrate and explain how energy and matter flow in the zombie fire system during a fire. Use the following prompts to help students prepare to develop their models: * * *

- What are the components of the zombie fire system?
- Where are matter and energy in these components?
- How do the components work together (interactions)?
- How are energy and matter flowing through these interactions?
- What can explain what is happening behind the scenes between the components (mechanisms)?
- What is included as part of the system and what is not?
- What is outside the zombie fire system?
- How can you use pictures, symbols, and/or words to show your ideas?

Encourage students to stop and jot any questions that bubble up for them as they develop their models, either in their notebook or on sticky notes. They will build a DQB at the end of the lesson, and these questions may be useful as students develop DQB questions. If students get stuck on how to start their models, have them turn and talk to a partner or pull them into a quick whole-class discussion. Ask them to focus first on the components or parts of the system and go through some of the categories they identified on *Arctic Fire Noticings/Wonderings*. Next, ask them how those components affect each other in zombie fires.

* SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

In high school, students build on their middle school use of systems and system models where they modeled energy flows in systems. Here they should begin to identify the boundaries of the zombie fire system, what is included and what is beyond it. This will lead them to begin to consider what other systems surround the zombie fire system and how those systems interact.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Make sure students know that it is okay if they do not know the right answer when developing models. At this stage, all ideas and questions are welcome. The goal of developing an initial model is to make their thinking visible. Have students try to put any ideas they are thinking down on paper. They can use pictures, symbols, and/or words to illustrate the relationships between components. Encourage them to add question marks in places where they are not sure of the relationship or need more information about the unseen mechanism behind an interaction.

* ATTENDING TO EQUITY

Emerging Multilingual Learners: If some of your students have not had the chance to learn about components, mechanisms, and interactions, take a moment to introduce these terms to students now.

Until students are comfortable with these terms, consider moving interchangeably between student-friendly language (such as

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Student models that explain incomplete understandings about the flow of matter and energy in the zombie fire system, including: **Evidence** from the images, videos, data, and reading that shows **energy** and **matter flow within** the zombie fire **system and outside it**, (such as plants, peat, snow/ice, fire, temperature changes, and atmosphere) including: (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)

- A potential mechanism for how **peat** could be releasing **carbon dioxide** when **burning**. (DCI: LS1.C.3; CCC: 4.3)
- Warmer temperatures in the zombie fire system mean more zombie fires burning for longer, and releasing more **carbon dioxide** might also mean more forest **fires** or more **carbon dioxide** released in general. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)
- Zombie fires being able to burn for a long time or the fires having enough **energy** to burn all winter/underground. (CCC: 4.3)
- Cold temperatures that have fire burning under ice, **warmer average temperatures** near the Arctic, greater **carbon dioxide** emissions in 2020, and **peat** deposits pictured **burning** at -60 degrees Celsius outside and releasing **smoke** from underground. (SEP: 1.4; DCI: ESS2.D.3; CCC: 4.2)

What to do: Circulate around the room as students develop their initial models with a clipboard and roster. Check off who has matter and energy arrows (or the other agreed-upon representation) on their models. Make note of whether or not individual students identify the peat/permafrost and carbon dioxide as both matter and energy that flow from one form to another via fire. Also note whether student models include any matter and energy flowing out of the zombie fire system. Check in with individual students as the class develops their consensus model and later in Lesson 3 when students revise it to see who has made progress and who needs support. Prompt students with the following:

- Where is the matter and energy here?
- How can you represent it?
- How do the energy and matter flow?
- How can you represent it?
- What is the zombie fire system? What is outside of it?

If students get stuck, push them to use the evidence they examined from the visual inquiry to add new components and interactions to their models. Walk around the room with a clipboard and roster, check off who has matter and energy arrows on their models. When you come back, check and see who has made progress.

Building toward 1.B.1 Develop a model to explain how **matter (peat)** and **energy (fire)** flow in the zombie fire system. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)

Share individual initial models in small groups. Display slide O. Divide students into groups of 3. Give students several minutes to discuss noticings and wonderings from their initial model following the Talking Sticks protocol or another protocol used for sharing in your school/district. To begin each round, everyone puts their writing utensil (talking stick) in the middle of the circle. Then they track who has had a turn by picking up their writing utensil after they speak and removing it from the circle.

- Round 1: When given the start signal, one person picks up their pencil as a talking stick and then uses their model to explain their answer to the question: *How do matter and energy flow within the zombie fire system during a fire?* As each person shares, think about how this compares with other models you have seen (including your own). Repeat this for each person.
- Round 2: Once everyone has had a turn, put your talking sticks in the middle again and then one by one pick up to have each person share at least one similarity and difference they noted between the models and explanations that were shared.

COLLABORATION



This talking sticks protocol is helpful for making space for each student to share their ideas with the group. As students are getting familiar with working together, this protocol can help value each student's contribution and make sure air time is balanced.

parts to describe components) to allow students to develop meaning of these new terms.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Describe examples and non-examples by using a productive comparison. For example, a similarity might be that both students put smoke going into the air. If one student colored the smoke gray and another student did not color the smoke at all, that is a difference. However, this difference might not be as helpful for understanding as the differences between students' ideas, such as where the smoke was going to or coming from. Encourage students to look for meaningful differences and encourage them to think about how they might use the differences they noticed to revise their own models.

Compare similarities and differences. Display **slide P**. Tell students to record similarities and differences in their notebooks between their models and other group member's models. * Encourage students to write down any similarities, differences, or questions from other students that might inform revisions of their initial models.

9 · REVISE INDIVIDUAL INITIAL MODELS

4 min

MATERIALS: science notebook

Revise initial models. Display **slide Q**. Give students a chance to revise their models before building a class consensus model. This can help students articulate how their thinking changed as they learned from classmates' ideas and can also help them more effectively advocate for their ideas during the consensus discussion. Encourage students to use the feedback and questions they received from their peers in the previous step.

10 · DEVELOP INITIAL CONSENSUS MODEL

13 min

MATERIALS: science notebook, chart paper, chart paper markers

Gather in a Scientists Circle to develop an initial consensus model. Ask students to form a Scientists Circle, a horseshoe shape oriented toward the initial consensus model chart papers, and to bring their science notebooks with them.

SCIENTISTS CIRCLE



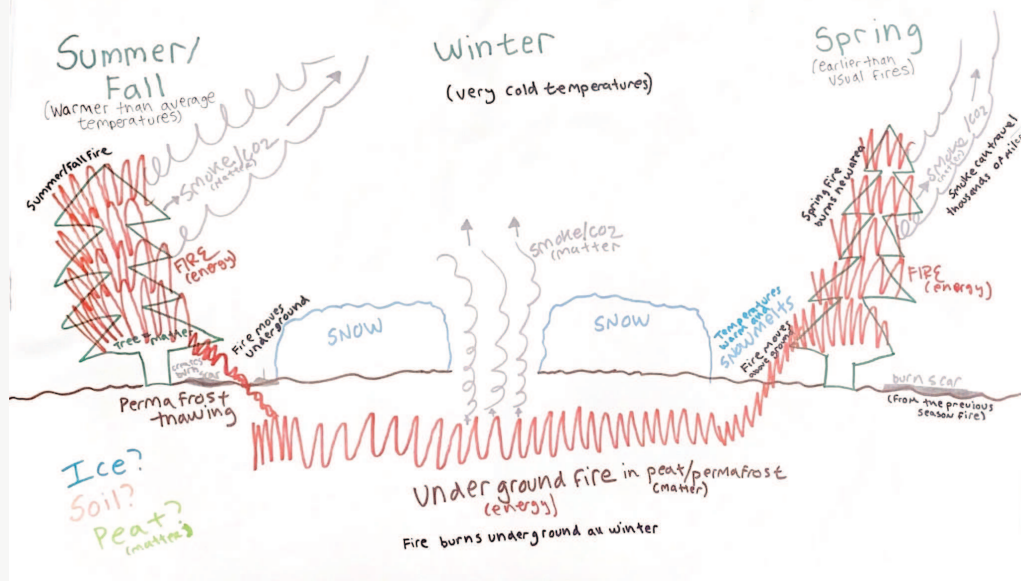
Your students may be familiar with the Scientists Circle from a previous unit. You will form a Scientists Circle in this lesson and many future lessons. Setting up the Community Agreements and logistics for forming, equitably participating in, and breaking down that space is important to do now if this is your first time forming such a space. Having students sit in a circle so they can see and face one another can help build a sense of shared mission and a community of learners working together. Returning to this Scientists Circle throughout the course of the unit to take stock of what the class has figured out and where they need to go next will be an important routine to help students take on greater agency in steering the direction of their learning. This circle will also help students build a sense of pride in their work. You may want to inform students that professional scientists collaborate with one another to brainstorm, discuss, and review their work also.

Debrief similarities and differences in initial models. Display **slide R** and put up two pieces of chart paper. Invite students to briefly share the similarities and differences they wrote in their science notebooks. Begin with writing the similarities on the first piece of chart paper.



Represent areas of agreement and disagreement in an initial consensus model. On the second piece of chart paper, build an initial class consensus model to explain how zombie fires can burn under the ice, releasing so much carbon. An example is shown below. Throughout the discussion, and again toward the end, remind students to record any questions they have in their science notebooks so that they do not lose those questions.

How are Zombie Fires burning under ice and releasing so much carbon?



ADDITIONAL GUIDANCE

The crosscutting concept *energy and matter* is intentionally developed in this unit. Students may already know and be able to represent energy and matter in their models based on their experiences in middle school. It will be necessary in the upcoming discussion to push students to come to consensus on how to represent the flow of energy and matter within the zombie fire system (and later in the unit both molecular-level and larger-scale systems). In the unit, you will see wavy lines representing the flow of energy and dashed, straight lines to represent the flow of matter. This convention may vary slightly from what your students suggest and that is okay, as long as you establish a way to differentiate and identify both energy and matter and use it consistently throughout the unit. Consider adding this convention as a key on your consensus model or to Personal Glossaries.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Students **develop models to explain** their current understandings about the flow matter and energy in the zombie fire system. **Model is based on evidence** from the images, videos, data, and reading that shows **energy and matter flow within** the zombie fire **system and outside it** (such as plants, peat, snow/ice, fire, temperature changes, and atmosphere), including: (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)

- A potential mechanism for how **peat** could be releasing **carbon dioxide** when **burning**. (DCI: LS1.C.3; CCC: 4.3)
- Warmer temperatures in the zombie fire system mean more zombie fires burning for longer, and releasing more **carbon dioxide** might also mean more forest **fires** or more **carbon dioxide** released in general. (DCI: LS1.C.3; CCC: 4.3)
- Zombie fires being able to burn for a long time or **energy** in the system to burn all winter/underground. (CCC: 4.3)
- Cold temperatures that have fire burning under ice, **warmer average temperatures** near the Arctic, greater **carbon dioxide** emissions in 2020, and **peat** deposits pictured **burning** at -60 degrees Celsius outside and releasing **smoke** from underground. (DCI: ESS2.D.3; CCC: 4.2)

What to do: Use your checklist from the initial model development to check in with individual students about their understanding of energy and matter in the zombie fire system. For students who need additional support, point them back to the visual inquiry and their initial model for evidence to add to the class consensus model. Some students may benefit from developing a consensus model in a small group before developing the whole-class consensus model.

Building toward 1.B.2 **Develop a model to explain how matter (peat) and energy (fire) flow in the zombie fire system.** (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)

Suggested prompt

Sample student response

In order to help us better understand what is happening with zombie fires, let's think back to the work we did in OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit). What were the ecosystems we studied?

We studied the Serengeti.

We studied the biodiversity of ecosystems that needed conservation.

What were the boundaries of those systems?

Serengeti National Park.

Other parks.

Mountains, oceans, or other landscapes.

What is the boundary of the system described in the zombie fires phenomenon?

The zombie fires are happening in one ecosystem with the components (such as with the peat, permafrost, etc.). There are multiple systems that have zombie fires (like Alaska and Siberia).

There is air in the system, so the air (and smoke) can travel out of the system to other places.

Suggested prompt	Sample student response	
<i>What is outside of the zombie fire system?</i>	The Arctic. The air. The planet.	
Say, So I hear you saying that there are several different levels or scales in zombie fire systems. Let's start by examining all of the parts or components in a single zombie fire system, and then we can move out from there to larger-scale systems. *		
Suggested prompts	Sample student responses	Follow-up questions
<i>What are the components of the zombie fire system?</i>	Peat. Permafrost. Fire. Smoke. Animals. Plants. Trees. Air. Snow/ice.	<i>How does matter cycle within a zombie system?</i> <i>How does energy flow within a zombie fire system?</i>
<i>How do the components work together (interactions)?</i>	The forest fires burn in the fall. There are warmer temperatures in the Arctic. The peat is in the thawing permafrost. When the permafrost thaws, the peat burns. The smoke comes up from underground and goes into the air, releasing carbon dioxide. In the spring, the temperature is cooler and the fires from underground can come above ground and become forest fires, burning more plants and other structures.	<i>What happens to matter in this system?</i> <i>Where does it come from? Where does it go?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>What can we explain about what is happening behind the scenes between the components (mechanisms)?</i>	There must be something about the peat that makes it able to burn under the ice.	<i>How is energy coming into/out of a zombie fire system?</i>
<i>How does our zombie fire system interact with other systems?</i>	Lots of carbon dioxide from the fire goes into the air. The smoke can travel for miles. More trees are getting burned down. Animals lose where they live and maybe food.	<i>How can we represent things we cannot see?</i> <i>What questions do we have now?</i>

COLLABORATION



Through a collaborative process--starting with individual, then group, and finally whole-class conversation--students develop and revise shared models that represent a class consensus. Emphasize productive and respectful discourse during group and class discussions to support collaboration by asking questions like:

- *Does anyone disagree with the idea presented?*
- *Is there anything about the phenomenon that we have not explained yet? Are there any gaps that need filling?*

11 • NAVIGATE

5 min

MATERIALS: science notebook

Record new questions. Show **slide S**. Have students write down new questions they are now thinking about for how zombie fires can burn under ice, releasing so much energy and matter. They should write them in their science notebooks before they leave class or on a separate paper to be collected and passed back at the beginning of the next class period. They should come to the next class prepared to share those questions with others.

Let the class know that at the next session we will share all of our questions and build a DQB to help figure out what is going on with zombie fires.

End of day 2

MATERIALS: None

Return to the questions students generated earlier and develop new questions. Say, *Last class, we brainstormed a lot of questions about how zombie fires could be burning under ice and releasing energy and matter. Today, we are going to post zombie fire questions to our Driving Question Board and begin thinking about how we are going to investigate what is happening in the system or what causes zombie fires to happen.* If you collected student questions at the end of the last class, pass them back now.

Write initial questions for the Driving Question Board. Display **slide T**. Pass out three sticky notes to each student. Say, *We have a lot of great questions about how zombie fires can burn under ice and release lots of carbon dioxide, and we are ready to create our Driving Question Board (DQB).* Let students know that the DQB will help keep the class organized and keep track of what we want to know and what we figure out throughout the unit. Instruct them to write up to three questions each, one per sticky note, using their science notebook resources as a guide.

*

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Have students write their initials and L1 on the back of their sticky notes for the DQB so that you can compare their progress as they use the science practice *asking questions* throughout the unit.

13 · BUILD THE DRIVING QUESTION BOARD

18 min

MATERIALS: 3x3 sticky notes, chart paper markers, chart paper

Gather in a Scientists Circle. Ask students to form a Scientists Circle, a horseshoe shape oriented toward the DQB, and to bring their sticky notes with them.

ADDITIONAL GUIDANCE

If this is the first DQB of the year, consider spending time establishing the process. Explain to students that one of the purposes of our unit is to answer the questions we have about these fires, and in order to know our class mission we have to determine what we need to figure out. Go over the steps outlined on **slide T** and emphasize that the students lead the creation of the DQB. Remind students that if they have a question but do not want to share their questions verbally, they can ask someone else to share their questions or ask you to add to the DQB at the beginning of the next class period.



Students create a Driving Question Board. Display **slide U**. Explain to the class that you would like for them to take responsibility for creating the DQB and that the process for doing so is described on the slide. You might want to choose the first volunteer to begin the process and then step back. Step in when necessary to point students to some of the class community agreements that encourage equitable participation. The student-facing directions for assembling the DQB include:

1. Choose a volunteer to go first, read their question, and put it on the DQB.
2. Raise your hand if you have a question that is related or the same.
3. The first volunteer selects the next student whose hand is raised. The student who is called on reads the related question, says why or how it relates, and then moves it onto the DQB with the original question.
4. That student selects the next student who will read another related sticky note, move it, and then call on the next student.
5. Continue until the class agrees that all the related questions have been placed. Continue until everyone has shared at least one question.

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

As students create this Driving Question Board, they ask questions that arise from careful observation of phenomena to clarify and/or seek additional information. Be mindful of the kinds of questions students ask in this initial lesson; for example, pay attention to how many are open (i.e., not a yes/no answer) versus closed (i.e., yes/no answer).

* SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

If students get stuck in the generation of new questions, use the consensus model to focus students on places in the system where few questions have been asked. Ask students to think about parts of the system that seem important but are hard to explain, such as how the zombie fires happen and how energy and matter flow in the system. Ask students to think about things they want to explore about the flow of matter and energy to see if they can contribute to understanding the system. These prompts

Suggested prompt	Sample student response	may get students thinking about additional questions they have about the zombie fire system and the relationship between systems.
<i>What questions do we have about zombie fires and how they can burn under the ice?</i>	What is peat? Why is peat burning? What is permafrost? What is needed for fires to burn/how does fire happen? What makes a big or small fire? Are the fires getting worse or better? Is there something we can all do to be safer from fire, no matter where you live? What happens to the animals in forest fires? Can fires ever be good? How do the zombie fires start? How do zombie fires burn for so long? How do zombie fires get hot under ice? Are there more fires now than there were before temperatures increased? How can we prevent the spread of fire? How does the carbon dioxide/smoke from the fire affect places, lands, and waters, species, kinds, and behaviors of living things? How can smoke go across the country? What happens to all the smoke? Do some plants need fire? Are zombie fires a result of climate change or have they always been around? What percentage of the fires come from human disruption? Is it meant to burn or was it human interaction that had created that problem? How do the animals and humans impact the fires? Do humans contribute to zombie fires in ways other than global warming?	

Suggested prompt

Sample student response

Is there some type or fuel or a gas that the permafrost lets off when it melts?

Label the questions. After all students have shared their questions, you will have several different clusters of questions on the DQB. As a class, decide on labels for sets of questions based on topics. **

Title the DQB. Once everyone has contributed to the DQB, ask, *Can we articulate a main question that we will answer by investigating all these questions?* Listen for ideas such as, *How can fires burn under ice and release so much carbon?*, *What causes zombie fires to burn?*, or *What causes fires in ecosystems to burn?*

When a potential driving question arises, repeat it aloud and ask, *Do you think that by answering this question, we will have answers to most of the questions on our Driving Question Board?* Look for agreement using a show of hands and then write the chosen question at the top of the DQB with a chart paper marker.

SCIENTISTS CIRCLE



You will form a Scientists Circle in this lesson and many future lessons. Setting up the Community Agreements and logistics for forming, equitably participating in, and breaking down that space is important. Having students sit in a circle so they can see and face one another can help build a sense of shared mission and a community of learners working together. Returning to this Scientists Circle throughout the course of the unit to take stock of what the class has figured out and where they need to go next will be an important tool in helping the class take on greater agency in steering their learning. You may want to inform students that professional scientists also collaborate with one another to brainstorm, discuss, and review their work.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Questions (SEP: 1.4) about:

- Changes in **energy and matter** in the fire, peat, permafrost, **carbon dioxide**, and the **atmosphere**. (DCI: ESS2.D.3; CCC: 5.2)
- **The zombie fire system and surroundings/other interacting systems** that include **carbon dioxide**, fire, temperature, snow/ice, and the **atmosphere**. (DCI: ESS2.D.3; CCC: 5.2)
- **Human interactions** that **change the biosphere and atmosphere** in ways that increase fire potential and the **addition of carbon dioxide to the atmosphere**. (DCI: ESS2.D.3; CCC: 5.2)

What to do: Point students to the class consensus model to help them make sense of how their questions about the system would support developing that model as an explanatory tool for this phenomenon.

Building toward 1.C Ask questions to clarify how the **flow of energy and matter in the atmosphere (CO2/smoke) and biosphere(peat/permafrost)**, allows zombie fires to burn, **including the role of humans**. (SEP: 1.4; DCI: ESS2.D.3; CCC: 5.2)

14 · CONSIDER IDEAS FOR INVESTIGATION

10 min

MATERIALS: science notebook, chart paper, chart paper markers

Generate ideas for investigation. Congratulate students on generating a productive board full of great questions. Let them know that the next step is to brainstorm ideas that will help us figure out how to answer those questions. As this may be a new practice for students, ask them to focus on the questions related to mechanisms allowing zombie fires to burn under ice. They should focus on one question at a time and generate ideas for how they could go about answering each question. Their first instinct may be to “do research.” Prompt them to be more specific and answer questions about what specific data they would need to answer each question. Consider modeling an example to get them started.

Display **slide V**. Give students two minutes to generate ideas for investigation in their science notebooks. Encourage students to think about how we might generate the evidence we need to answer the questions that we have. If there is time, give them a minute to talk with a partner before sharing with the whole class. Record student ideas on a list on the whiteboard or chart paper titled “Ideas for Investigation”.

Publicly display students’ ideas for investigation. Ask individual students or pairs of students to share their ideas for investigation. Publicly display student ideas for investigation on the whiteboard or on a piece of chart paper for the class to have as a reference.

Suggested prompt	Sample student response
<i>What kind of investigations could we do?</i>	We could watch documentaries or videos. We could read some scientific articles. We could research it. We could try burning peat or other things that burn in fire. We could see what was in the smoke.
<i>What additional sources of information would we need to help us answer our questions?</i>	We need to know what is in peat and what is in the smoke. We need to know more about the permafrost and what is happening to it. We need to know what is happening to the different organisms. We need to know if there are other fires happening and know more about fires in different ecosystems.

15 · INTRODUCE AND UPDATE PROGRESS TRACKERS

7 min

MATERIALS: *Fires Progress Tracker*

Propose starting a Progress Tracker to keep track of ideas. Say, *As we are looking at our initial models, the questions we had, and the ideas for investigations we thought of so far, it is also clear there are many things that we have already started to figure out, and we did not yet get a chance to add them to our Progress Trackers. Let’s take some time to do that now, and it will also refresh our memories so we can get a productive start on some of these investigation ideas today.*

* ATTENDING TO EQUITY

Supporting emergent multilinguals: Allow and encourage students to use both content-specific and everyday registers

Distribute Fires Progress Tracker. Display slide W. Say, *When we were creating our initial models, we realized we would need to collect a lot more evidence. If we had a place to keep track of all the ideas and patterns that we might eventually use as evidence to support our claims, that would be really helpful.*

Have students add the unit question from the DQB to the top box on *Fires Progress Tracker*. Then read the column titles:

- What I figured out/ What questions do I have now?
- How does WWFO connect to me or my community or have a larger-scale impact?
- How does what we figured out help us answer our Driving Question about fires?

Say, *Think about the ideas about the potential components, interactions, and mechanisms we uncovered when doing the visual inquiry and creating an initial model of the zombie fire. We can use the Progress Tracker to help us think across the 5 dimensions of the visual inquiry. We can also use the Progress Tracker to help us make sure the investigations we do in each lesson connect back to what we wanted to figure out about zombie fires.*

Give students 3-5 minutes to record ideas in their Progress Trackers while you circulate around the room to see students' thoughts so you will be able to summarize them when you come back together. One possible representation of a completed Progress Tracker is shown below. *

	What we figured out (WWFO)	How does WWFO help us make progress on our Driving Question about zombie fires?	How does WWFO connect to me or my community, or have a larger-scale impact?	What questions do I have now?
Lesson 1: How can fires burn under ice and release so much carbon?	-Zombie fires burn under ice throughout the winter. -In zombie fires, peat is burning in the thawing permafrost. -Lots of carbon is put into the air when these zombie fires burn. -Zombie fires are not very common but are becoming more common.	We need to know more about what is happening with the matter and energy that allows zombie fires to burn underground!	If these new zombie fires are burning, are there other new fires happening elsewhere?	- What is peat? - Why is peat burning? - What is permafrost? - What is needed for fires to burn/how does fire happen?

when expressing their ideas. Switching back and forth between different registers is especially important for emerging multilingual students because it helps them draw on their full range of meaning-making resources. Students who are learning English also benefit from redundancy of content and vocabulary. Revisiting the learning from the previous unit provides them with that opportunity here.

16 • NAVIGATE

5 min

MATERIALS: chart paper, chart paper markers

Students prioritize what question(s) to answer next. Display slide X. Say, *We have a lot of questions that we want to try and find the answers to over the next several weeks. We also have a great list of ideas for how to investigate those questions.* Remind students of the unit Driving Question similar to, *What causes (zombie) fires to burn?* and post it above the Driving Question Board on a piece of chart paper. Ask them to review the DQB and their initial ideas for investigations with that Driving Question in mind. After a minute, ask students to share what question they think the class should investigate next. As students identify specific questions or groups of questions, keep a record of which questions the class thinks should be answered next. Prompt the class to consider what aspects of the class model are most incomplete and increasingly motivated to understand the mechanisms better; specifically, listen for questions about what peat and permafrost are and how their role as components of the zombie fire system could allow fires to burn under ice. *

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

As the class is asked to describe how answering specific questions would support the class in developing their model, encourage them to evaluate the questions to determine if they are relevant and testable.

Ask students to Turn and Talk. Ask students to turn to a partner and, based on the ideas for investigation everyone we just co-constructed, share their ideas for what would be productive for the class to investigate next. Consider taking a moment to acknowledge that what we collect to burn is part of an ecosystem and taking it away could impact the ecosystem. Have students think about if we were to gather peat or other things burning in wildfire samples, how could we make sure to do so ethically.

Suggested prompt	Sample student response
<i>What are our next steps? What investigations do you propose?</i>	We want to burn peat. We want to observe peat and permafrost. We want to find out what is in the smoke by testing it. We want to know more about if peat is fuel for the fires.
Thank students for sharing their ideas and tell them that the class will start the next lesson by taking a closer look at burning peat and what else is happening in zombie fire systems.	

ADDITIONAL GUIDANCE

Other fire samples (fuels) to burn can be collected from a variety of places: home gardens, wood piles, dried sticks, brush piles, raked leaves, dead flower bouquets, greenhouses, bags of charcoal. Try to collect these at least a week in advance so they have time to dry out in a paper bag. Peat is the only required material. Gather at least two additional local plant fuels for students to examine. Please note that while fuel is likely being used by students to describe different things in this lesson it will not be co constructed and added to personal glossaries until Lesson 2.

Consider the role of dead plants in the ecosystem. Butterflies, bees, and other important pollinators overwinter in dead leaves, hollowed out stems, and decaying wood.

Additional Lesson 1 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RI.9-10.10

Range of Reading and Level of Text Complexity: By the end of grade 9, read and comprehend literary nonfiction in the grades 9-10 text complexity band proficiently with scaffolding as needed at the high end of the range.

Students obtain information from reading nonfiction texts in the *Arctic Fire Noticings/Wonderings* and *Arctic Fire Visual Inquiry* (<https://docs.google.com/presentation/d/1C-eQj7P1NX9ig71X4C1oxVK7tCkc2zPEB93rOtk5gfc/edit?usp=sharing>).

LESSON 2: What is peat and why does it burn so much?

PREVIOUS LESSON *We did a visual inquiry to investigate zombie fires. We shared our experiences and ideas about how our lives are connected to fires. We developed initial models to explain the interactions in the zombie fire system and how they release so much carbon. We developed a DQB and decided to investigate how zombie fires could be burning under the ice.*

THIS LESSON

INVESTIGATION

2 days



We decide to investigate what is burning in zombie fires. We observe peat and other fuels, read about peat, and burn peat and other fuels for fire. We wonder why there is so much peat that has not decomposed in the Arctic.

NEXT LESSON *We will plan and carry out an investigation using yeast as a model organism to generate evidence and investigate the work of scientists to generate evidence to construct an explanation.*

BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



WHAT STUDENTS WILL DO

2.A Select appropriate tools to collect and record data in an ethical manner about the flow of energy and matter from the biosphere to the atmosphere as a result of burning. (SEP: 3.3 & 3.4; DCI: LS1.C.3; CCC: 5.4)

WHAT STUDENTS WILL FIGURE OUT

- We can explain puzzling observations using energy and matter concepts.
- Peat, made from ancient plants, is widespread and used as fuel.
- Peat is carbon-based and releases CO₂ when burned.
- Peat burns slowly, emitting much CO₂ and energy.
- Permafrost is ground that stays frozen for years, even centuries.
- Arctic permafrost thaw reveals peat.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Revisit what we figured out in the last lesson.	A	
2	5 min		BRAINSTORM FUEL SOURCES AND CONSIDER ETHICS Use Related Phenomenon to generate ideas for additional fuel sources and consider the ethics of burning.	B-E	Community Agreements
3	8 min		OBSERVE WILDFIRE FUEL SAMPLES Support noticings and wonderings about peat and other dry fuel samples.	F-G	<i>Matter/Energy Question Cards</i> , Community Agreements, Observation of Fuels
4	4 min		INITIAL IDEAS DISCUSSION ABOUT FUEL SAMPLES Facilitate an Initial Ideas Discussion about observations and predictions about fuel sources.	H	whiteboard, dry erase markers
5	10 min		READ ABOUT PEAT Facilitate a notice and wonder and turn and talk about a peat reading.	I-K	<i>Peat, Permafrost, Carbon</i>
6	12 min		DEVELOP AN INVESTIGATION PLAN Generate ideas for tools and methods for recording data during investigation.	L-M	<i>Investigation Planning Workspace</i>
7	3 min		NAVIGATE: REVISE INVESTIGATION IDEAS	N	<i>Investigation Planning Workspace</i>
End of day 1					
8	2 min		NAVIGATE Review what we figured out and our next steps.	O	
9	5 min		REVIEW CLASS INVESTIGATION PLAN Share a class investigation plan.	P	
10	8 min		DESIGN A DATA TABLE Support the class in designing a data table.	Q-R	
11	18 min		CONDUCT DEMONSTRATION OF BURNING FUELS Collect data about matter and energy changes while observing a variety of wildfire fuel samples burn, including peat.	S	Burning Fuels Investigation
12	8 min		BUILDING UNDERSTANDINGS DISCUSSION ABOUT BURNING FUELS Facilitate a discussion about what we figured out from the Burning Fuels Investigation.	T-U	whiteboard, dry erase markers
13	4 min		NAVIGATE: UPDATE PROGRESS TRACKERS Support students in updating Progress Trackers with new ideas about peat, energy, and matter in the zombie fire system.	V-W	<i>Fires Progress Tracker</i> (from Lesson 1)

End of day 2

Lesson 2 • Materials List

	per student	per group	per class
Observation of Fuels materials	science notebook	- peat - samples of dried plants - magnifying glass - dissecting microscope (optional)	
Burning Fuels Investigation materials	- safety goggles - non-latex apron - nitrile gloves - science notebook		- Bunsen burner - fireproof tongs - matches or lighter - peat chips - samples of dried plants - bromothymol blue 0.04% aqueous solution 1 liter of distilled water - Windex - eye dropper or pipette 250 ml flask - Petri dishes (60x15) - one quart Pyrex™ storage containers - aluminum foil sheets - drinking straw - timer - gram scale - infrared thermometer
Lesson materials	- science notebook <i>Investigation Planning Workspace</i> <i>Fires Progress Tracker</i> (from Lesson 1)	<i>Matter/Energy Question Cards</i>	- Community Agreements - whiteboard - dry erase markers <i>Peat, Permafrost, Carbon</i>

Materials preparation (10 minutes)

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

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

Be sure your Community Agreements are visible for reference during this lesson.

Three-hole-punch all handouts so they can be added to student notebooks. Print and cut a set of *Matter/Energy Question Cards* for each small group.

Make sure a whiteboard and dry erase markers or equivalent are available to make a public record of the Matter-Energy Chart during Initial and Building Understandings Discussions.

Day 1: Observation of Fuels

- Group size:** 4-5 students.
- Setup:** Using the class's decisions for ethical sample collection, collect 3 or 4 other fuel samples available locally, such as dried leaves, dried grasses, charcoal, wood, and/or sticks. Do this at least a week in advance if fuels need time to dry. Provide each group with a pan, tray, or large plate holding a piece of peat from the kit plus other fuels. Peat, grasses, and leaves

can be crumbly, so the container will make it easier to transport.

- **Notes for during the investigation:** See *Burning Fuel Samples* for additional information.
- **Safety:**
 - Wear safety goggles (specifically, indirectly vented chemical splash goggles), a non-latex apron, and nitrile gloves during the set-up, hands-on investigation, and take-down segments of the activity.
 - Wash your hands with soap and water immediately after completing this activity.
 - Never eat any food items used in a lab activity.
 - Never taste any substance or chemical in the lab.
 - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- **Disposal:** All fuels can be stored and reused for future classes. Return fuel samples you collected to the location where they were found if not being stored.
- **Storage:** Keep fuels away from ignition sources such as electrical outlets, matches, etc.

Between Day 1 and Day 2: Prepare the demonstration. Modify the protocol provided in *Burning Fuel Samples* to add items like thermometers, oxygen or carbon dioxide probes, or a scale based on what students suggest during the discussion.

Day 2: Burning Fuels Investigation

- **Group size:** Students will observe a demonstration for the investigation.
- **Setup:** To dilute the 0.04% BTB solution, add 25 mL of BTB (straight from the container) to a 1000 mL beaker. Add distilled water to the beaker until it reaches the 1000 mL line. The BTB solution should appear blue in color. If it does not, add a base, like Windex or NaOH, one drop at a time. Swirl after adding each drop and repeat as needed to create a blue color. Keep Windex on hand during the experiment to keep the starting color blue. Use aluminum foil to protect the table surface if necessary. Collect materials needed: 3 1-quart glass containers, fuel samples, Bunsen burner or stove, matches or lighter, fireproof tongs, beaker, flask, straw, Petri dishes. Have an infrared thermometer and a gram scale available if students decide they want to use them in the experiment.
- **Notes for during the investigation:** Do not use tap water to mix BTB, as minerals may prohibit the indicator from functioning properly. Use distilled water.
- **Safety:**
 - Use a vented hood when burning materials.
 - Ensure burning materials have cooled completely before disposal.
 - Ensure that the classroom has engineering controls (eyewash station and shower) available.
 - Wear indirectly vented chemical splash goggles, a non-latex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
 - Make sure students wear indirectly vented chemical splash goggles during the demonstration.
 - Make sure students are a safer distance from the burning materials - at least 15+ feet during the demonstration.
 - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
 - Immediately wipe up any spilled water on the floor--it is a slip and fall hazard.
 - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
 - Wash your hands with soap and water immediately after completing this activity.
 - Never eat any food items used in a lab activity.
 - Never taste any substance or chemical in the lab.
 - The BTB solution is not hazardous, but if it comes into contact with the skin or eyes, rinse thoroughly with water for 15-20 minutes. If swallowed, get medical attention.
 - Make sure that your school/district fire safety policies are in place with either water buckets, safety showers, and/or a fire extinguisher, ready to use.
- **Disposal:** Disposal should be in accordance with applicable regional, national, and local laws and regulations. Local regulations may be more stringent than regional or national requirements.
- **Storage:** Keep fuels away from ignition sources. Tightly seal the BTB bottle and store the container of BTB in a cool, dark place reserved for chemical storage. BTB can be stored at room temperature with a shelf life of approximately 36 months. Diluted BTB solution can be saved for use in Lesson 3.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students investigate the flow of energy and matter when peat and other fuels burn to collect evidence that peat contains a great deal of matter and energy that can burn during a zombie fire.

From middle school and earlier grade bands, students should be familiar with the following ideas:

- *Substances are made of different atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.* (MS PS1.A)
- *The amount (weight) of matter is conserved when it changes form, even in transitions where it seems to vanish.* (3–5 PS.1.A)
- *The total number of each type of atom is conserved, and thus the mass does not change.* (MS PS1.B)
- *Substances react chemically in different ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.* (MS PS1.B)

Guidance is provided in the lesson to support students who are not familiar with prior grade band ideas.

Students use the science practice *planning and carrying out investigations*. In middle school, students should have had experience evaluating the accuracy of various methods for collecting data. These methods may have been selected by the teacher. Here they develop the use of this practice by participating in the process of selecting the appropriate tools themselves. They also use this practice in a new way as they consider the ethical implications of their investigation plan.

Students use the crosscutting concept *energy and matter* as they identify how energy and matter flow as fuel burns. They build on the middle school practice as they track the flow of energy and matter together driven by burning within the fuel system and the zombie fire system.

In this lesson, students co-construct the definitions for *fuel*, *peat*, *energy*, and *matter*. They encounter a definition for *permafrost*. Words should be defined and recorded in Personal Glossaries AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

In this lesson students do not derive the equation for combustion or investigate the chemistry of why certain materials burn more easily or hotter than others. While methane is an important greenhouse gas that can be released from melting permafrost, explaining the unit phenomenon does not require methane, and it is excluded from the unit. Students who have demonstrated mastery of the ideas in this lesson may benefit from an extension related to the role of methane in the zombie fire system. Use <https://youtu.be/rRbSdYf8Sok?si=WixsDWfoYGaqVikw> to support these students.

Students who express interest in this topic could investigate methane production in the arctic permafrost or consider a locally significant source of methane emissions and what is being done to reduce those emissions. Some examples of methane emission sources include the production and transport of fossil fuels including “orphan” wells, the cultivation of livestock and agricultural practices, and the anaerobic decay of organic waste in municipal solid waste landfills. Efforts to reduce these emissions include community organizing to cap abandoned wells, shifting agricultural practices and diets, and diverting organic waste from landfills through home or municipal composting.

Students will figure out why certain materials burn more easily and hotter than others in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, and *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)* where they will also address the role of methane as a greenhouse gas.

LEARNING PLAN for LESSON 2

1 · NAVIGATE

3 min

MATERIALS: science notebook

Review what we did and figured out last time. Display *slide A*. Ask students to review their science notebooks and reflect individually about what they remember doing and figuring out in Lesson 1. Invite a few students to share what they remember about the questions the class was curious about at the end of the previous class and ideas for investigating those questions.

Suggested prompt	Sample student response
<i>What did we do and figure out in the last class?</i>	We learned about zombie fires that are burning in the Arctic. We wrote questions for our DQB. Permafrost is thawing and peat is burning under the ice. Temperatures are increasing. Carbon dioxide and smoke are going into the air.
<i>What are our next steps?</i>	We want to burn peat to figure out what it is and how it can burn under the ice. We want to know more about permafrost.
<i>How will burning peat help us understand the flow of energy and matter in the zombie fire system during a fire?</i>	How much it burns might tell us how much energy it has. If it turns into ash or smoke, we can see what happens to the matter.
<i>How can we use the ideas we discussed when we talked about related phenomena to help us make progress on our questions?</i>	We have not seen zombie fires, but we know a lot about fires from other places that can help us predict what happens when things burn.

2 · BRAINSTORM FUEL SOURCES AND CONSIDER ETHICS

5 min

MATERIALS: science notebook, Community Agreements

Turn and talk about requirements for fire. Display *slide B*. Say, *You all have a lot of great ideas about investigating peat and you have a lot of ideas about how fires burn from the related phenomenon. Let's take a minute to think about what the necessary components are for a fire to burn.* Ask students to turn and talk to a partner about the requirements for fire. Call on a few pairs to share their ideas. Listen for students to share ideas such as fuel, heat, oxygen, and/or a spark.

*** ATTENDING TO EQUITY**
Building classroom culture: This is an optimal time to consider revisiting the Community Agreements, and it is an

Notice and wonder about the fire triangle. Display **slide C**. Say, *You all had some great ideas about what we need for a fire. I want to introduce you to a tool called the fire triangle that gives us a way to think about how your ideas relate.* Ask students to stop and jot their ideas down in response to the questions on the slide. Then call on a few students to share their ideas.

Suggested prompts	Sample student responses	Follow-up questions
What do you notice?	Fire needs oxygen, heat, and fuel.	What would happen if one of the components were missing?
What do you wonder?	Where does the spark happen?	How might the heat be related to the spark/ignition?
Where does peat fit in?	Peat is a fuel.	Are all fuels the same?
What other fuels are involved in fires in ecosystems?	Wood, grass, trees, etc.	What ecosystems did we identify in our Related Phenomenon as places that have fires?

ADDITIONAL GUIDANCE

The fire triangle is often used in fire prevention education. Students may be familiar with the fire triangle from their lived experiences. Take a moment to ask students if they have seen the fire triangle before and in what context. Identifying connections between the classroom and students' lives can help support student interest and help students see how what they figure out in science class is relevant to their lives.

Add fuel to Personal Glossaries. Display **Slide D**. Say, *We have been talking a lot about fuel. Before we move forward, let's make sure we have a common definition of fuel.* Call on a few students to share a definition of fuel and revise until the class agrees on a common definition. Pause to give students a moment to enter this into their Personal Glossaries. Definitions may look similar to: *something with a lot of energy in it that can burn.* *

Introduce ethical considerations. Display **slide E**. Let students know that in the past there have been situations when scientists have done harm to the environment by taking specimens without considering the consequences. Also, some communities have cultural values or beliefs that prohibit taking things from the environment without permission or the proper ceremony or procedure. Say, *How can we make sure that by gathering and burning the fuel samples we are being responsible?* Listen for responses such as:

- *We would want to make sure we were not damaging anything living.*
- *We would want to make sure we were not disrupting the habitat of other living things.*
- *We would want to make sure when we burn it, we do so safely and do not put bad stuff into the air too much.*

important opportunity to emphasize that each individual has contributions to make to their community of learners. It is through differences in thinking that the class will grow their knowledge together. Throughout this unit, students will be asked to be open to sharing knowledge products that depict their current thinking and to be open to learning from classmates who share their knowledge too.

3 · OBSERVE WILDFIRE FUEL SAMPLES

8 min

MATERIALS: Observation of Fuels, *Matter/Energy Question Cards*, Community Agreements

Set up a Matter-Energy Chart. Say, *Since our goal is to track the flow of energy and matter in the zombie fire system, let's make sure we consider the matter and energy in our fuel samples.* Display **slide F** and guide students in developing a Matter-Energy Chart similar to what is on the slide. Pause to make sure students have a common definition for matter and energy and give them a moment to add those definitions to their Personal Glossaries.

ADDITIONAL GUIDANCE

In the NGSS, matter and energy are introduced early in the K-2 and 3-5 elementary school grade bands. From their experiences in school and their everyday lives, students will likely be familiar with these terms. However, it is important for the class to have a common understanding of their definitions as they progress through the unit. Encourage students to describe matter by classifying the observable and unobservable parts of materials they observe and energy by considering moving objects at both the macro and microscopic scales.

Introduce fuel samples. Explain that you gathered some fuel samples before today's class. Describe to students steps you took to gather fuel samples in a responsible way. Summarize any steps you took to ethically gather the samples, or reflect aloud on what you might do differently next time given the ideas students shared at the start of class.

Organize students into groups of 4-5 students. Distribute the fuel samples, magnifying glass, and/or dissecting scope for observation.

Small groups observe fuel samples and make predictions. Ask students to record their observations and predictions in their Matter-Energy Charts in their science notebooks. Students can make their observations independently or discuss with group members. As students examine the fuels, circulate to talk with students about their thinking.

Ask probing questions about matter and energy. After students have had about 5 minutes to make initial observations, display **slide G** and read the questions from the slide. Then say, *I have prepared some cards with questions that will help us pay attention to matter and energy during our investigation today. If you start running out of ideas while making observations and predictions, draw a card from the deck and use the question to push your thinking.* While students work, circulate to ask the follow-up questions in the deck *Matter/Energy Question Cards*.

ADDITIONAL GUIDANCE

From middle school, students should be familiar with the idea that *substances are made of different atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms* (MS PS1.A). If students are not familiar with these ideas, spend a few minutes reviewing atoms and molecules in the context of the peat and the other fuel samples.

4 · INITIAL IDEAS DISCUSSION ABOUT FUEL SAMPLES

4 min

MATERIALS: science notebook, whiteboard, dry erase markers

Initial Ideas Discussion about fuel observations and predictions. After students have looked at samples, bring the class back together to briefly share their observations and predictions. Use a whiteboard and whiteboard markers to make a public record of the discussion. Display **slide H** and use the prompts below as a guide. Answers will vary based on available fuel samples. *

* STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

Reasons for eliciting students' initial ideas include:

- To get students' prior knowledge and experiences on the table.

Suggested prompts	Sample student responses	Follow-up questions
<i>What did you notice about the different fuels for fire?</i>	Peat is dark black, a bit crumbly, bits of something in it, maybe dried grass? Leaves look dead and dried out. Answers will vary based on fuel sources.	<i>What kinds of material might each fuel be made of? How similar or different are they at the observable scale?</i>
<i>What do you think the fuels are made of? What is inside the fuel that you cannot see?</i>	Plants. Cells, molecules, carbon.	<i>What kinds of molecules, elements, or atoms might make up those materials?</i> <i>Where is the energy in the fuel? In what form(s) might the energy exist?</i>
<i>What will happen to the energy and matter in the fuel sources as they burn?</i>	When the fuel burns, the energy will get used up. When the fuel burns, its matter will turn into smoke and ash. Some of the fuels have more energy and will burn longer/release more smoke/make more fire.	<i>Which fuel might release more energy when burned? Why do you think so?</i> <i>Which fuel might make more smoke or other byproducts when burned? Why do you think so?</i> <i>Think about what types of atoms or molecules the fuels might be made of. If they are made of those atoms or molecules, what do you think the smoke or other byproducts of the fire will be made of?</i>

KEY IDEAS

Purpose of discussion: To build initial claims about energy and matter in peat and other fuel sources from evidence.

Listen for these ideas:

- Peat is made of plants.
- Peat and other fuels are made of molecules and atoms.
- Fuels have energy in them.

- To provide a supportive opportunity for students to make sense of what may not be fully formed ideas (either their own ideas or those of others).
- Help students realize that there are gaps in our understanding to promote curiosity and what we could do next to figure something out.

5 · READ ABOUT PEAT

10 min

MATERIALS: science notebook, *Peat*, *Permafrost*, *Carbon*

Consider how to figure out more about peat. Say, *It sounds like we are pretty sure peat is made from plants and have some ideas about what types of atoms it is made of, but we are not totally sure. To make responsible decisions about how to burn the fuels, it seems important to be sure about what exactly we are burning. We are still more familiar with other fuels. What else can we do to figure out more about peat?* Listen for students to suggest doing research, reading, or watching videos. Tell students that you do have copies of a short reading about peat available today.

Build a list of guiding questions for reading. Display **slide I**. Distribute *Peat, Permafrost, Carbon* to each student. Say, *One question we have is, What is peat made of? What other questions do you have about peat that we should look for answers to?* Record guiding questions that the class generates in a public space and invite students to record these questions in their notebooks. As they generate their questions, remind students of the lesson question, *What is peat and why does it burn so much?* and the class focus on energy and matter.

Read about peat. Display **slide J**. Give students time on their own to read and record answers to their questions in their notebook using whatever reading strategy is in place in your classroom.

ALTERNATE ACTIVITY

Literacy and Comprehension Support. For students who benefit from additional reading comprehension support, the Coherent Reading Protocol is well suited for this text. The Coherent Reading Protocol guides students to monitor their understanding after each chunk of text, identify the main idea, and connect the information in the reading to the lesson question. The Coherent Reading Protocol can be found in the Teacher Handbook.

Sensemaking with partners. Ask students to turn and talk to a partner about the questions they answered in their science notebooks. Refer to **slide K**. Call on a few pairs to share their thoughts. Use the questions on the slide as a guide.

6 · DEVELOP AN INVESTIGATION PLAN

12 min

MATERIALS: science notebook, *Investigation Planning Workspace*

Introduce the Burning Fuels investigation and consider ethics. Remind students that they wanted to burn peat and now that they have made some observations and predictions and gathered additional information, the class is ready to plan and carry out an investigation. Say, *We thought that burning the samples would be important to answering our questions about the role of peat in zombie fires. But now we know that peat is basically densely packed plant matter and that burning peat releases so much carbon into the atmosphere that even places that have long cultural practices of burning peat are moving away from this practice.* Display **slide L** and use the prompts below as a guide.

Suggested prompt	Sample student response
<i>How can we balance our need for data with the potential impacts of burning so much fuel?</i>	We need to be sure we collect the data we need while burning the sample so we do not have to do it multiple times.
<i>How can we reduce the amount of carbon dioxide we produce while also generating enough data to answer our questions?</i>	We could do the test as a class, instead of each person doing the test. We could watch videos of these tests instead. We could take a video or slow motion video so we can watch the investigation again.

Individual idea generation about tools to measure changes in energy and matter. Display **slide M** and distribute *Investigation Planning Workspace*. Say, *You all have some great ideas about how we can measure changes to energy and matter.* Refer back to student suggestions from the previous activity. These may include ideas about measuring temperature or measuring the carbon in the smoke. Ask students to individually record their ideas on their handouts. Invite many students to share their ideas and discuss the benefits and drawbacks of various tools. If students have difficulty coming up with ideas, take a few moments to have students talk about their ideas with a partner. Call on a few pairs to share their ideas using the prompts below as a guide.

Suggested prompts	Sample student responses	Follow-up questions
<i>What evidence can we collect to help us understand changes in energy as the fuels burn?</i>	We can burn the fuel and measure the temperature change. We can measure how long it burns. How big, small, or bright the flame is would tell us about the energy.	<i>What can we observe to understand changes in energy as the fuels burn?</i>
<i>What tools could we use to collect that evidence?</i>	We can put water over the flame and see how much the water heats up while the fuel burns. We could use thermometers. We could observe the flames (make illustrations, take photos or videos) to see them more closely.	<i>Have you used or observed any tools that could help us collect this evidence?</i>
<i>What evidence can we collect to help us understand changes in matter as the fuels burn?</i>	We can collect the smoke and measure it somehow. If there are sugars (carbon) in the fuel, we can see if there is carbon in the smoke. We can somehow measure what is left after it burns.	<i>What does the matter in the peat look like during and after burning?</i> <i>What is inside the fuel? What is it made of?</i> <i>What does the fuel turn into as it burns?</i>
<i>What tools could we use to collect that evidence?</i>	A carbon dioxide measuring tool. We could take before and after photos. We could weigh the fuel before and after burning. Some way to catch the smoke.	<i>Have you used or observed any tools that could help us collect this evidence?</i>
<i>What differences do you think you will see between peat and the other fuel sources?</i>	Maybe the peat will burn longer or have more smoke. There might be differences in how long it takes them to light or what the flame looks like. Answers will vary based on fuel source.	<i>How is the peat different from the other fuels?</i>

ADDITIONAL GUIDANCE

Students should have worked with energy and matter in elementary and middle school science classes. For students who need additional support with these ideas, prompt students to think of prior grade band ideas about conservation of energy and matter:

- *The amount (weight) of matter is conserved when it changes form, even in transitions where it seems to vanish.* (3–5 PS.1.A).
- *The total number of each type of atom is conserved, and thus the mass does not change.* (MS PS1.B)
- *Substances react chemically in different ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.* (MS PS1.B)

If students experienced the OpenSciEd Middle School program, they may have experience using BTB in *OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*, Lesson 11. They also may have investigated burning oil in open and closed systems in *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)* Lesson 11.

7 · NAVIGATE: REVISE INVESTIGATION IDEAS

3 min

MATERIALS: science notebook, *Investigation Planning Workspace*



Revise individual ideas. Display **slide N** and ask students to revise their ideas on *Investigation Planning Workspace* based on the class discussion.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Evidence of energy and matter flow when burning, such as matter in peat recombining to form carbon dioxide and water. (SEP: 3.4; DCI: LS1.C.3; CCC: 5.4)
- Ideas for tools to collect evidence of the flow of energy and matter when burning fuel samples. (SEP: 3.4; DCI: LS1.C.3; CCC: 5.4)

Note: At this stage students need only to suggest a tool that makes sense, e.g., a device to measure carbon dioxide. They do not need to name a specific kind of tool.

What to do: Following the class discussion, invite students to review their responses and then collect *Investigation Planning Workspace*. Sort student responses to inform grouping for the Burning Fuels investigation on day 2. Use the following three categories as a guide to sorting student responses:

1. Students who demonstrate an understanding of evidence of energy AND matter and have at least one idea for a data collection tool.
2. Students who demonstrate an understanding of how to collect evidence of energy OR matter with or without an idea for a data collection tool.
3. Students who do not yet demonstrate an understanding of what could be considered evidence of energy and matter changes with or without an idea for a data collection tool.

On day 2, use the piles to create groups that distribute students from each pile across groups.

Building towards 2.A.1 Select appropriate tools to collect and record data in an ethical manner about the flow of energy and matter from the biosphere to the atmosphere as a result of burning. (SEP: 3.3 & 3.4; DCI: LS1.C.3; CCC: 5.4)

End of day 1

8 • NAVIGATE

2 min

MATERIALS: science notebook

Review what we figured out and our next steps. Display slide O. Call on a few students to share what the class figured out and next steps. Listen for the following:

- Peat is made of plants, which are made of sugar-containing carbon, oxygen, and hydrogen.
- When it burns, it releases carbon dioxide.
- We want to measure changes to energy and matter when peat and other fuel burns by using tools.

9 • REVIEW CLASS INVESTIGATION PLAN

5 min

MATERIALS: science notebook

Introduce the investigation plan. Display slide P. Say, *I used what you suggested yesterday to make a protocol to follow while we burn the fuels today.* Review the plan on the slide and ask students to turn and talk about what evidence we are collecting today and how that evidence will help us answer our lesson question: *What is peat and why does it burn so much?* Invite students to turn and talk to a partner, then call on a few students to share their thoughts. *

 **Discuss the use of BTB as an indicator for carbon dioxide.** Say, *There are many ways to detect if carbon dioxide is present. One way to measure it is by using a chemical called bromothymol blue or BTB.* Some students may recall using it in middle school investigations. Explain that BTB changes from blue to yellow when carbon dioxide is present. When carbon dioxide dissolves in water, it forms a molecule called carbonic acid, and BTB turns yellow in acidic water. Demonstrate how this happens by asking one student to gently blow through a straw into a flask with 100-150 ml of BTB that is blue. Any student volunteer should wear protective eyewear and should be instructed not to ingest the BTB solution. They will see it slowly turn from blue to green, then yellow. Introduce any other tools the class will be using for data collection, such as a thermometer and a scale.

SAFETY PRECAUTIONS



BTB should not be inhaled or ingested. Remind students to wear safety goggles during this investigation. See materials preparation for additional safety guidance. Do not allow students to handle NaOH or other strong bases used to turn BTB blue. If you prefer not to have a student demonstrate this, use https://youtu.be/_ivfgYDbVQU?si=AoRk1PSvNNax8TgO to demonstrate how blowing into BTB changes the color. Absent students can also watch this video.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

As students develop their use of this practice, it is important for them to have the opportunity to select the appropriate tools to collect, record, analyze, and evaluate data. In middle school, students should have used this practice to evaluate methods for accuracy. As students select tools, encourage them to consider how one method may be more accurate than another and that we may choose a method that offers less accuracy due to classroom constraints. Tools such as carbon dioxide or oxygen probes may offer more accuracy. BTB can be used to produce similar data with the potential for less accuracy.

10 • DESIGN A DATA TABLE

8 min

MATERIALS: science notebook

Make a specific plan for how to track matter and energy. Say, *The class worked together to generate ideas for how to track energy and matter as the fuels burn.* * Display slide Q and call on a few students to respond to the questions on the slide. Listen for students to suggest organizing their evidence or data in a format such as a table.

* SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

Throughout this lesson, bring your questioning back to the cycling of matter and energy. Here we ask students how they will track carbon (matter) and energy as they



Turn and talk to design a data table. Say, *Let's make sure we are prepared to keep track of what we observe. Think about the tools and measurements we just discussed as part of our investigation plan.* Display **slide R** and ask students to work with a partner to create a data table in their science notebooks that will allow them to keep track of the energy and matter as the fuels burn. Use the prompts below to support their thinking:

- What tools are we using to collect evidence about matter/energy?
- What kinds of data will we collect using that tool?
- Do we need evidence of matter/energy before, during, and after we burn the fuel?

Whole-class discussion about data collection. Allow many students to share their ideas. Come to consensus about the data the class should collect and ask students to revise the data table in their science notebooks. A sample data table can be found below. Your class data table may vary based on the class investigation plan.

		Sample 1	Sample 2	Sample 3
Energy	Fuel temp before			
	Fuel temp after			
	Surrounding temp before			
	Surrounding temp after			
	Burning time			
	Other observations			
Matter	Mass before			
	Mass after			
	BTB before			
	BTB after			
	Other observations			

burn materials. Ask questions such as: *Where did the carbon come from? What happened to the energy? What caused the carbon to move from one place to another?*

11 • CONDUCT DEMONSTRATION OF BURNING FUELS

18 min

MATERIALS: Burning Fuels Investigation

 **Burn fuels for fire.** Display **slide S**. Burn fuel samples using the instructions provided in *Burning Fuel Samples*. Have students record their observations in their science notebooks for each fuel burned. They should record observations for what they suggested, for example, changes in BTB color, changes in temperature, and differences in relative measurements across the samples. Emphasize qualitative observations for this investigation (such as *BTB turned from blue to yellow, showing an increase in carbon dioxide*) rather than measuring exactly how much it increased, but modify if students are interested in quantitative measurements, such as mass change.

SAFETY PRECAUTIONS



Review the safety guidelines for this demonstration. Ensure adequate ventilation. Make sure that your school/district fire safety policies are in place with water buckets, safety showers, and/or a fire extinguisher, ready to use. Wear safety goggles and make sure all students also wear safety goggles.

ADDITIONAL GUIDANCE

Consider using a document camera and projector to increase visibility of the demonstration. If you run your own burn demonstrations, your class noticings may vary slightly from the demonstration video, <https://youtu.be/wm--7z88KjQ>. Do not be concerned with discrepancies in terms of temperature rise or how quickly the BTB changes color, or if it only turns green, not yellow. The materials we are burning are not uniform in make-up, and the procedure did not emphasize burning equivalent masses or volumes.

Peat takes a long time to ignite. Draw student attention to this and invite them to consider why it is harder to light the peat than the other samples. Once peat is burning, it burns for a long time, and is difficult to put out. Again, invite students to speculate as to why this might be.

12 • BUILDING UNDERSTANDINGS DISCUSSION ABOUT BURNING FUELS

8 min

MATERIALS: science notebook, whiteboard, dry erase markers

 **Discuss observations.** Display **slide T**. Ask, *Now that we have burned the fuels, what have we figured out?* Give students a minute to think independently and then share with a partner or group before discussing it as a class. Use the discussion prompts below and on **slide U** to help students to build on each others' ideas. Use a whiteboard and dry erase markers (or equivalent) to make a public record of the discussion. Following the discussion, consider inviting students to self-assess on their contribution using *Discussion Self-Assessment* **

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful kind of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and claims and push them to support these conclusions and claims with evidence. Students can disagree with each other, and the class does not need to reach consensus on all ideas shared. Areas of disagreement

Suggested prompts	Sample student responses	Follow-up questions	
<i>What happened to the matter in each of the fuels? What evidence do you have?</i>	The fuels themselves changed in color. Where there was ash it was white/gray. The mass reduced after burning. The peat's mass reduced the most. Maybe most of the atoms were rearranged into the smoke. Some droplets formed on the glass, especially when burning the peat.	<i>What did the fuel start out as?</i> <i>What did the fuel look like after burning?</i> <i>What is the fuel made of that we cannot see?</i>	can motivate future investigations. Helpful prompts during these kind of discussions include: <i>When clarifying ideas and pressing for reasoning:</i> • Can you say more about that? • What do you mean when you say the word "_____ "? • Who can add onto this idea? • Who has a different way of thinking about this topic? • Can you think of an instance when that was not the case?
<i>What happened to the energy in each of the fuels? What evidence do you have?</i>	It went from the fuel to the air and surface nearby. We measured the change in temperature, and the temperature went up. We saw the flame.	<i>What does the temperature change tell us about energy?</i> <i>What does the light from the flame tell us about energy?</i>	<i>When supporting students to build on each others' ideas</i> • Who can repeat or rephrase what _____ just said?
<i>We saw condensation form, and noticed that the flames went out pretty quickly when we covered the fuel. What might be going on here?</i>	Fire needs oxygen. Maybe the oxygen got used up and the flame went out? The sugars in the fuels have oxygen and hydrogen atoms in addition to carbon. Maybe those became water droplets?	<i>What is the smoke made of?</i> <i>Where did the water come from?</i>	
<i>What differences did you notice about the matter and energy in peat during burning?</i>	Peat burned for longer than the other fuels. The temperature change was greater for peat. The BTB had a greater color change; more carbon dioxide was produced.	<i>What were the differences between the peat and the other fuels?</i>	
<i>How does this evidence help us explain the zombie fire system?</i>	There is more energy in matter in the peat than in other fuels so the zombie fire can burn for a long time.	<i>What does it mean that the peat burned longer than other fuels?</i> <i>Why was the BTB more yellow with the peat?</i>	

* ATTENDING TO EQUITY

Universal Design for Learning: This is a great opportunity for students to self-assess their *engagement* in classroom discussions using *Discussion Self-Assessment*. This discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day.

Suggested prompts	Sample student responses	Follow-up questions
<i>How could the tools we selected have affected the accuracy of our evidence?</i>	The BTB gave us a color change, but it did not tell us a specific amount of carbon dioxide. The dish system was not totally closed, so we may not have collected all of the smoke/carbon dioxide, heat, etc. Answers will vary based on specific class protocols.	<i>For what we wanted to figure out, was it okay that we did not measure an exact amount of carbon dioxide/have a completely closed system, etc.?</i>
<i>How was carrying out the investigation as a class an ethical choice?</i>	Burning peat puts a lot of carbon dioxide in the atmosphere, so we do not want to burn a lot.	<i>What other opportunities do individuals and society have to make ethical choices about burning fuels?</i>

KEY IDEAS

Purpose of discussion: To build initial claims about the question, *What is peat and why does it burn so much?* from evidence collected from burning it in comparison to other fuels.

Listen for these ideas:

- All the fuels have **carbon-based molecules** in them, but peat seems like it might have even more because the **BTB solution turned more yellow**, more carbon inside peat=more **carbon dioxide** in air. (SEP: 3.3; DCI: LS1.C.3)
- All the fuels **produce energy** because we saw **light and measured a rise in temperature** when they burned, but peat kept burning for longer. (SEP: 3.3; CCC: 5.4)
- The **burning moved the matter from the sugar molecules in the fuel to the carbon dioxide and water molecules in the atmosphere**. (DCI: LS1.C.3; CCC: 5.4)
- **We did not need to track the exact amount of carbon dioxide**. Using the color change gave us relative amounts.(SEP: 3.4)
- Doing the investigation as a class was an **ethical decision to keep excess carbon out of the atmosphere**.(SEP: 3.3)

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: See Key Ideas above.

What to do: If students are struggling to track the matter and energy in the peat and other fuels, organize them into small groups to develop models to explain how energy and matter flow as the fuel burns. Encourage them to do the following:

- Use straight lines to show matter and wavy lines to show energy flow as they did in the class consensus model.
- Include the matter and energy they cannot see (including molecules and atoms).

Building towards 2.A.2 **Select appropriate tools to collect and record data in an ethical manner about the flow of energy and matter from the biosphere to the atmosphere as a result of burning.** (SEP: 3.3 & 3.4; DCI: LS1.C.3; CCC: 5.4)

13 · NAVIGATE: UPDATE PROGRESS TRACKERS

4 min

MATERIALS: science notebook, *Fires Progress Tracker* (from Lesson 1)

Synthesize our ideas about peat, energy, and matter in the zombie fire system. Say, *We figured out a lot, and we still have some unanswered questions about what is going on with the peat in the zombie fire system.*

Add peat to Personal Glossaries. Display slide V. Say, *We made a lot of progress on our lesson question, What is peat and why does it burn so much? Let's add a definition for peat to our Personal Glossaries.* Give students time to come to consensus on a definition and record it in their Personal Glossaries. Definitions may be similar to: *carbon-based plant material, made of long chains of sugars that has been under the permafrost for many years and has not decomposed.*

Update Progress Trackers. Display slide W. Give students time to add their ideas from this discussion to the *Fires Progress Tracker* from Lesson 1. One possible representation of a completed Progress Tracker is shown below.

	What we figured out (WWFO)	How does WWFO help us make progress on our Driving Question about zombie fires?	How does WWFO connect to me or my community or have a larger-scale impact?	What questions do I have now?
Lesson 2: What is peat and why does it burn so much?	- Peat forms when plants die year after year, fall to the bottom of a wetland, and get buried over thousands of years. For some reason, the plants do not break down and store lots of carbon and energy. - Permafrost is frozen plants and animals, and ice and peat can be frozen inside it. When permafrost melts, it releases carbon-containing gasses. Peat can be frozen inside permafrost and burned when it thaws.	Peat contains carbon that is released into the atmosphere as carbon dioxide when it burns. The peat must be storing lots of energy somehow because it can burn and release heat and light.	I am worried that peat and permafrost store huge amounts of carbon that are starting to be released by the fires and warming temperatures. Won't that affect climate change and pollute the air in my community? People around the world are responsible for the rising temperatures that are causing these fires. We should think about the consequences of our actions.	-Why didn't the vegetation that formed peat decompose? -How did peat and permafrost come to store so much carbon?

ADDITIONAL GUIDANCE

When students think about how to update their Progress Trackers, bring up questions related to the five dimensions of complex social-ecological framework, such as thinking across scales or ethical deliberation and decision-making, by asking them to consider some of these ideas:

- How long do you think it took to build up the permafrost?
- Who is responsible for the thawing of the permafrost? Whom will it impact?

Please note this framework was adapted from: Learning in Places Collaborative (2022). Framework: Complex Socio-Ecological Systems. Bothell, Seattle, WA & Evanston, IL: Learning in Places. Please see <http://learninginplaces.org/frameworks/complex-socio-ecological-systems-framework/> for further information and guidance.

Additional Lesson 2 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-Literacy -RST.9-10.1 Support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

Students use a reading to obtain precise details about peat, its composition, and how it is made.

LESSON 3: Why is there so much peat that has not decomposed in the permafrost?

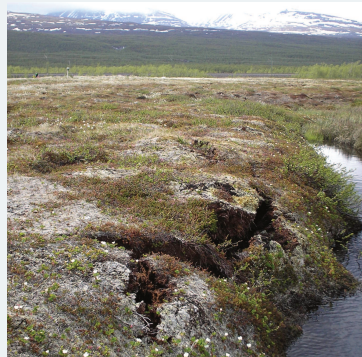
PREVIOUS LESSON

We decided to investigate what is burning in zombie fires. We observed peat and other fuels, read about peat, and burned peat and other fuels for fire. We wondered why there is so much peat that has not decomposed in the Arctic.

THIS LESSON

INVESTIGATION

4 days



Dentren, CC BY-SA 3.0

We decide to investigate why there is so much peat in the Arctic that has not decomposed. We plan and carry out an investigation using yeast as a model organism to generate evidence. We figure out that temperature affects the rate of decomposition/cellular respiration. We investigate the work of scientists who figured out that oxygen is also involved in the rate of decomposition/cellular respiration. We construct an explanation based on evidence. We wonder how all that peat got there in the first place.

NEXT LESSON

We will explore a puzzling idea: that there is a lot of energy and matter in the cold, snowy Arctic, where we do not expect it. We will recall what we know about photosynthesis, relate photosynthesis to solar radiation, and read about Earth's conditions in the past and how they could have contributed to all of the energy and matter in the peat in the zombie fire system.

BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



WHAT STUDENTS WILL DO

3.A Plan and carry out an investigation to produce evidence of changes to **matter and energy flows in and out of a system during cellular respiration** under different conditions. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)

3.B Construct an explanation for factors that affect **cellular respiration**, resulting in changes in **the flow of matter and energy** in the zombie fire system. (SEP: 6.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Energy and matter from plants are typically returned to the atmosphere by decomposers.
- Conditions such as temperature and oxygen levels affect the rate of decomposition.
- Decomposition happens through a process called cellular respiration, where energy and matter are transferred.
- Energy from sugar is transferred to yeast and other decomposers during cellular respiration.
- Matter from sugar is transformed during cellular respiration to grow more yeast and produce carbon dioxide and water.
- In the permafrost/peat system, cold temperatures and low oxygen levels slow the rate of decomposition and cellular respiration.
- When rates of decomposition are low, the matter and energy do not flow out of the permafrost/peat system, making a carbon sink.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Review, generate, and prioritize questions and next steps.	A	
2	5 min		INITIAL IDEAS DISCUSSION ABOUT DECOMPOSITION Facilitate an Initial Ideas Discussion about the conditions that are necessary for so much peat to remain locked in the permafrost.	B-C	
3	3 min		GENERATE IDEAS FOR INVESTIGATION Guide students to share ideas about investigations into matter and energy in the zombie fire system.	D	Lesson 1 consensus model
4	7 min		INTRODUCE A MODEL DECOMPOSER AND MAP TO THE ZOMBIE FIRE SYSTEM Lead a discussion about yeast as a model organism for decomposition.	E-I	
5	12 min		PLAN DECOMPOSITION INVESTIGATION, PART 1 Organize students in small groups to begin to plan their Decomposition Investigation.	J-K	<i>Decomposition Investigation Planning</i>
6	13 min		PLAN DECOMPOSITION INVESTIGATION, PARTS 2 AND 3 Prompt students to take up the next steps in investigation planning.	L-M	<i>Decomposition Investigation Planning</i>
7	2 min		NAVIGATE Facilitate a reflection and revision of investigation plans.	N	
<i>End of day 1</i>					
8	3 min		NAVIGATE Revisit students' investigation plans.	O	<i>Decomposition Investigation Planning</i>
9	9 min		REVIEW THE INVESTIGATION PLAN AND SAFETY CONSIDERATIONS Distribute investigation plans and ask students to review.	P-R	<i>Decomposition Investigation Data and Sensemaking</i>
10	25 min		CARRY OUT DECOMPOSITION INVESTIGATION AND CLEAN-UP Support student data collection and model development.	S-U	<i>Decomposition Investigation Data and Sensemaking, Decomposition Investigation</i>
11	5 min		NAVIGATE Ask students to share and compare their group's investigative questions, what they figured out, and what questions they still have with results from other groups.	V	<i>Decomposition Investigation Data and Sensemaking</i>
<i>End of day 2</i>					
12	5 min		NAVIGATE Facilitate a brief discussion about what the class figured out in the Decomposition Investigation and what questions remain.	W	<i>Decomposition Investigation Data and Sensemaking</i>

Part	Duration		Summary	Slide	Materials
13	13 min		SMALL-GROUP WORK USING MOLECULE CARDS TO REPRESENT MATTER AND ENERGY FLOW Facilitate small-group work with molecule cards.	X	<i>Decomposition Investigation Data and Sensemaking, Sensemaking: Matter Energy Cards, Matter Energy Cards, 3x3 sticky notes</i>
14	12 min		BUILDING UNDERSTANDINGS DISCUSSION ABOUT MATTER AND ENERGY FLOW USING THE MOLECULE CARDS Lead a Building Understandings Discussion about how energy and matter flow at the molecular level in the zombie fire system.	Y-Z	
15	10 min		SMALL-GROUP SENSEMAKING ABOUT OXYGEN AND CELLULAR RESPIRATION Support small-group sensemaking around the role of oxygen in cellular respiration.	AA-DD	<i>Oxygen and Decomposition</i>
16	5 min		NAVIGATE: EXIT TICKET Organize students to complete an exit ticket.	EE	
<i>End of day 3</i>					
17	5 min		NAVIGATE Lead a brief discussion to review what students figured out in the last class.	FF	
18	10 min		CONSENSUS DISCUSSION ABOUT CELLULAR RESPIRATION IN THE ZOMBIE FIRE SYSTEM Facilitation a whole-class discussion to build consensus about why slow decomposition has created a carbon sink in the zombie fire system.	GG-HH	<i>Decomposition Investigation Data and Sensemaking, chart paper, chart paper markers</i>
19	10 min		REVISE CLASS CONSENSUS MODEL Guide students in revising the class consensus model to include their new ideas.	II	
20	15 min		CONSTRUCT EXPLANATIONS FOR MATTER AND ENERGY IN THE ZOMBIE FIRE SYSTEM Support students as they construct individual written explanations.	JJ	<i>Peat/Permafrost Explanation, Peat/Permafrost Explanation Feedback Guidance</i>
21	5 min		NAVIGATE Capture new questions students have as they finish their explanations.	KK	
<i>End of day 4</i>					

Lesson 3 • Materials List

	per student	per group	per class
Decomposition Investigation materials	• safety goggles • non-latex apron • nitrile gloves	• 3 250 mL beakers • 100 mL cold water • 100 mL room temperature water • 100 mL warm water • 3 digital thermometers • 4.5 tsp/15 g yeast • 1.5 tsp/6 g sugar • metric ruler • 2 0.5 teaspoon measuring spoon • tape for labeling beakers (optional) • timer	• hot water • cold water • room temperature water
Lesson materials	• science notebook • <i>Decomposition Investigation Planning</i> • <i>Decomposition Investigation Data and Sensemaking</i> • <i>Sensemaking: Matter Energy Cards</i> • <i>Oxygen and Decomposition</i> • <i>Peat/Permafrost Explanation</i>	• <i>Decomposition Investigation Planning</i> • <i>Matter Energy Cards</i> • 3x3 sticky notes	• Lesson 1 consensus model • chart paper • chart paper markers • <i>Peat/Permafrost Explanation Feedback Guidance</i>

Materials preparation (30 minutes)

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

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

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

Be sure your Community Agreements and Lesson 1 Consensus Model are visible for reference during this lesson.

If you do not have access to the unit kit, print and cut out the cards in *Matter Energy Cards* for each group. You may want to laminate these as they will be used in Lesson 4 and can be reused.

Day 2: Decomposition Investigation

- **Group size:** 4-5 students.
- **Setup:** Gather materials for the Decomposition Investigation. These materials may vary slightly due to student choice. Ensure access to water of different temperatures (hot, cold, and room temperature).
- **Notes for during the investigation:** For additional information, see *Decomposition Investigation Preparation*.
- **Safety:** Students will be working with hot water. Ensure that students take appropriate precautions (including safety goggles, non-latex aprons, and nitrile gloves) and do not pour hot water into beakers. Use caution when working with heated liquids--these can burn skin! Immediately wipe up any spilled water on the floor--this is a slip and fall hazard.
- While yeast is generally safe for use, in case of inhalation, move to fresh air and rest; in case of contact with eyes, rinse immediately with water; after contact with skin, wash immediately; if swallowed, seek medical advice.
- **Disposal:** Dispose in accordance with all applicable federal, state, and local regulations. Always contact a permitted waste disposer to assure compliance. **Storage:** When not in use, store yeast and sugar in a cool, dry, and well ventilated place.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students build on the following middle school grade band ideas:

- MS LS2.B *Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.*
- MS L1.C.2 *Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy.*
- MS PS3.D.2 *Cellular respiration in plants and animals involves chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.*
- MS PS1.B *Gases and liquids are made of molecules or interim atoms that are moving about relative to each other.*
- MS PS1.A *In a liquid, molecules are constantly in contact with others.*
- MS PS3.A *The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule.*

Students build toward a complete understanding of the following HS DCIs:

- LS2.B.1: ~~Photosynthesis~~ and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- LS1.C.4: As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.

Photosynthesis and the remainder of LS2.B.1 will be investigated in Lesson 5.

Students intentionally develop the practice of *planning and carrying out investigations*. In middle school, students should have used this practice to identify independent, dependent, and control variables, necessary tools, and how much data is needed to make a claim. They revisit many of these elements and develop new elements, such as determining accuracy and limitations.

They also intentionally develop the practice of *constructing explanations*. They build on their middle school use, where they should have constructed explanations based on their own investigations by integrating additional sources of data and looking at the past, present, and future.

Students intentionally develop the use of the crosscutting concepts of *energy and matter* throughout the lesson to build on its use in Lesson 1 and to explain the flow of energy and matter in the zombie fire system.

Students co-construct a definition for *carbon sink*, which they should add to their Personal Glossaries. They encounter the terms *cellular respiration*, *aerobic* and *anaerobic*. They may choose to add these words as well. Some students may need to co-construct cellular respiration if they do not remember it from middle school.

Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students develop an understanding of cellular respiration, including the inputs and outputs oxygen, sugar, carbon dioxide, water, and energy. Balanced chemical equations, ATP, and chemical bond energetics are beyond the scope of the standards and the phenomenon. Students will explore: *Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangement of atoms into new molecules,, with the consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy* (HS PS1.B) in depth in OpenSciEd Chemistry.

When brainstorming inputs and outputs of cellular respiration during the Decomposition Investigation, students may conflate breathing and respiration and suggest that the yeast is “breathing.” Breathing is specific to inhalation and exhalation through structures like the trachea and lungs. Respiration is the chemical reaction carried out at the cellular level that yeast has in common with animals such as humans.

If students are motivated to go beyond the standards in this lesson, an optional reading *Frozen in Time* is available to extend their thinking about decomposition in peat that supports students in understanding other factors that contribute to peat being an effective carbon sink, such as pH.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

3 min

MATERIALS: science notebook

Facilitate a discussion about what we figured out in the last class. Display slide A. Say, *What did we figure out about peat and why it burns so much? What new questions do we have?*

Suggested prompt	Sample student response
<i>What did we figure out about peat and why it burns so much?</i>	Peat is made from dead plants, made of carbon. The peat requires oxygen to burn. Peat burns and releases lots of carbon dioxide. When peat burns, light and heat energy are released. When peat burns, water appears in the system. Warmer temperatures cause permafrost to melt, revealing more peat that can burn. It is hard to stop peat from burning, which could be why the zombie fires burned so long.
<i>What do we still need to figure out about the peat in the zombie fire system?</i>	Why is there so much peat? What is happening inside the permafrost? Why do plants and animals not decompose? Why is so much energy released when we burn peat? If the plant material in peat is hundreds or thousands of years old, why has it decomposed so little?

2 · INITIAL IDEAS DISCUSSION ABOUT DECOMPOSITION

5 min

MATERIALS: science notebook

Turn and Talk. Display **slide B**. Say, *We have lots of ideas about peat, permafrost, and zombie fires. We know peat releases energy and carbon dioxide when it burns, but we want to figure out: Why is there so much peat that has not decomposed in the permafrost?* Ask students to share with a partner their initial ideas in response to the question.

ADDITIONAL GUIDANCE

When students are trying to figure out what order to share, you may offer a few creative ways to initiate this engagement. Some of these ideas include: who woke up last this morning, whose birth month is closest to today (without going over), whose commute to school is longest (they will go second).

Facilitate a whole-class discussion. Have students share what was discussed in their pairs. Say, *I heard some great discussions as I walked around the room. Why do you think there is so much energy and matter in the peat in the Arctic today?* Use the prompts below and on **slide C** as a guide:

Suggested prompts	Sample student responses	Follow-up questions
<i>Why do you think there is so much peat in the permafrost?</i>	There must have been a lot of plants and trees over a long period of time. The Arctic is cold. There used to be a lot of water there. The plants that died did not decompose or break down all the way.	<i>What evidence did we have from Lessons 1 and 2 that might start to explain why there is so much peat today?</i>
<i>Why do you think so much matter and energy is released when peat burns?</i>	Somehow the energy is staying in the peat. The plants in the peat are not breaking down/decomposing.	<i>What conditions might be necessary to have peat that holds onto matter and energy for thousands of years?</i>
<i>We read that peat is formed from plants that do not completely break down. What do you know about how matter like plants breaks down?</i>	Bugs and worms and mold eat dead plants and break them down.	<i>What do we already know from middle school or our lived experiences about the process of living things breaking down other living or dead things?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>What conditions in the zombie fire system could affect decomposition and keep the matter and energy in the peat?</i>	The conditions keep everything frozen so it does not break down. Plants fell in the water, and the water stopped it from decomposing. There are not a lot of animals around to eat it. There are other living things that we maybe cannot see that break down dead things that are not in the peat/permafrost system usually. Maybe there is not enough oxygen.	<i>Why would falling in the water stop decomposition?</i>

ADDITIONAL GUIDANCE

Pause to come to consensus on a class definition of decomposition. Draw on students' middle school understanding. *Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments (MS LS2.B).* Students may use language such as *breaks down* or *rots* to communicate their understanding of the process of decomposition. If students do not initially bring up decomposition, prompt them to think about their previous experiences in school and/or in their own lives with matter and how it is broken down and recycled. For example, ask them to consider what happens to trees that die in a forest or leaves that fall from trees.

3 · GENERATE IDEAS FOR INVESTIGATION

3 min

MATERIALS: science notebook, Lesson 1 consensus model

Turn and Talk. Display **slide D**. Say, *You all shared a lot of great ideas about the factors that might contribute to the amount of matter and energy in the peat and the role of decomposition. How can we investigate how decomposition is involved in the flow of matter and energy in the zombie fire system?* Give students a few moments to talk to their partners and then ask pairs to share their thinking.

Listen for responses such as:

- We could watch peat (or other things) decompose/break down and try to measure matter and energy.
- We could set up an investigation to see how things decompose.
- We could put decomposing things in different conditions (cold, hot, wet, dry) to see what happens.
- We could set up the peat in warm and cold locations to see how it decomposes.

ADDITIONAL GUIDANCE

For students who do not have a middle school understanding of matter and energy flow through decomposition, it may be helpful to take extra time to review these concepts. *Optional: Banana Investigation* is provided as an optional investigation. Students will use photos of decomposing banana peels placed in different environments (open air, sealed in a bag with water, in soil, in a freezer) to make observations about changes they see over a 5-day period. Additional support for teaching about decomposition and cellular respiration at the middle school grade band is available in *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)* and *OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*. If students need support developing their middle school level planning and carrying out investigation practice, refer to *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*.

4 · INTRODUCE A MODEL DECOMPOSER AND MAP TO THE ZOMBIE FIRE SYSTEM

7 min

MATERIALS: science notebook

Introduce yeast as a model organism. Say, *Those are great ideas! I have a decomposer that is safe to use in our classroom, easy to get ahold of, and could help us investigate what happens to matter and energy during decomposition in a short period of time.* Hold up a packet of yeast and display **slide E**. Ask students if they have ever used yeast. Ask them to share any experience with yeast and how they use matter and energy. Listen for responses such as:

- It is used to make bread.
- You add sugar and flour and it makes dough rise when baking bread.

Circulate around the room with an open packet or jar so that students can see the yeast up close. Say, *The packet says that it is “live acting,” which means it is actually living.* Ask students to share ideas about what it means to be living. Listen for ideas such as:

- It needs oxygen, water, matter, and energy to survive.
- They reproduce and/or grow.
- They produce waste and/or carbon dioxide.

Turn and talk about matter and energy in yeast. Display **slide F**. Ask students to turn and talk about the question on the slide. Facilitate a brief discussion of how yeast interacts with matter and energy by first asking students to turn and talk to a partner about the question on the slide. Then call on a few pairs to share their thinking.

Suggested prompts	Sample student responses	Follow-up questions
<i>If yeast is a decomposer, how does it interact with matter and energy?</i>	It is eating something (matter). They change dead stuff into new things. They rearrange molecules in food into new things in their bodies. It is getting energy from some kind of food that is dead. They use carbon and energy in the sugar to grow.	<i>What happens to the matter during this process?</i> <i>What happens to the energy during this process?</i> <i>What happens that we cannot see when a decomposer eats something?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>In our model system we are going to feed the yeast sugar. Where is the matter and energy in the sugar?</i>	Carbon, hydrogen, oxygen. Glucose.	<i>What is inside the sugar that we cannot see?</i> <i>What do you remember from looking at what was inside the plant matter in Lesson 2?</i>

Share images of activated yeast and turn and talk. Say, *Now that we have some ideas about how decomposers like yeast interact in a system, let me show you how we can use them in our classroom. Yeast needs to be in water to be active. Here is what happens if you put yeast in water with sugar.* Display **slide G**. Ask students to turn and talk about what they observe when yeast and sugar are put together in the water. Listen for students to share ideas such as:

- The yeast are eating the sugar.
- The bubbles contain carbon dioxide.

Review the image on **slide G** from Lesson 2 that shows that sugar, or glucose, contains carbon, hydrogen, and oxygen and that plants, like those in peat, contain glucose.

Model mapping with yeast. Display **slide H**. Ask students to turn and talk to a partner about how the yeast system maps to our zombie fire system. Once students have had a few moments to discuss, call on a few pairs to share their thinking. See the chart below for sample model mapping.

Suggested prompts	Sample student responses	Follow-up questions
<i>What does the yeast represent?</i>	The decomposers in the peat.	<i>In Lesson 2, we read about peat formation. What did we find out?</i>
<i>What does the water represent?</i>	The water that the plants fall into in the peat.	<i>What form has the water in the zombie fire system been in for many years?</i> <i>What is happening to that water now?</i>
<i>What does the sugar represent?</i>	The peat. The plants in the peat. The energy/matter in the plant/peat.	<i>What did we see in our reading in Lesson 2 about the composition of plants?</i>
<i>What do the bubbles represent?</i>	The carbon dioxide. Whatever the sugar got converted into.	<i>Where did the bubbles come from?</i> <i>What happened to the matter/energy in the sugar?</i>
<i>What does the beaker represent?</i>	The zombie fire system. The peat/permafrost system.	<i>The beaker has all the things we are interested in studying. What does that represent?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>In the yeast system and the zombie fire system, where does the matter and energy flow from and to?</i>	From the sugar to the yeast. From the yeast to the carbon dioxide. From the (plants in the) peat to whatever eats the peat to the carbon dioxide in the atmosphere.	<i>Why does the yeast eat the sugar?</i> <i>What happens to any of the matter and energy in the sugar that the yeast does not use?</i> <i>The sugar is made of carbon, oxygen, and hydrogen. What does it turn into?</i>

This part of the yeast model...	is like this part of the zombie fire system ...
yeast	Decomposers in the peat (bugs, bacteria, etc.)
water	The water and ice in the peat/permafrost
sugar	Plant matter in the peat
bubbles	Carbon dioxide that goes into the air
beaker	Zombie fire system

Display **slide I** and review the model mapping.

ADDITIONAL GUIDANCE

Table sugar is actually sucrose, made from glucose and fructose. However, for the purposes of this lesson, we are equating sugar and glucose. High-interest students may be motivated to know more about the structure of sucrose and its relationship to glucose.

5 · PLAN DECOMPOSITION INVESTIGATION, PART 1

12 min

MATERIALS: *Decomposition Investigation Planning*

Begin investigation planning. Display **slide J** and distribute *Decomposition Investigation Planning* to each student. Say, *Earlier we said we were interested in an investigation to find out why matter has not decomposed in the permafrost. Now that we have our system mapped, let's start the planning process.* Let students know that the class is going to work together to answer the same question: *How does _____ affect the flow of matter and energy from _____ to _____ by decomposers in the zombie fire system?*

Small-group work to identify variables. Display **slide K**. Organize students into small groups of 3-5 students. Provide small groups with time to discuss and identify variables in *Decomposition Investigation Planning* and complete Part 1 of the handout. Circulate around the room and support their thinking. **

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

In middle school, students should have had opportunities to identify independent and dependent variables as they planned and carried out investigations. If this element of the practice is unfamiliar to students, take time to construct definitions to add to Personal Glossaries. Support them in using elements of the crosscutting concept *cause and effect* as they relate the independent variable to cause and the dependent variable to effect in the decomposition investigation and zombie fire system.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

An important element of planning and conducting an investigation at the high school level is to do so safely and in an ethical manner, including considerations of the personal, societal, and environmental impacts. Establishing safe and ethical scientific investigations as an explicit principle and referring to it often will help students start to use it as a default lens to evaluate what they or others propose to do before doing it, such as when they outline or critique the proposed plans for an investigation. Help students consider how model organisms, like yeast, can be used in service of ethical decisions in scientific investigations.

6 · PLAN DECOMPOSITION INVESTIGATION, PARTS 2 AND 3

13 min

MATERIALS: *Decomposition Investigation Planning*

Discuss investigation set-up. Display **slide L**. Let students know that in the investigation each group will have three beakers. Ask them to review Part 2 in *Decomposition Investigation Planning*, complete the questions, and turn and talk to a member of their group about what they think will stay the same between the beakers and what will change.** After students have had a chance to discuss, call on a few students to share their ideas.

Suggested prompts	Sample student responses	Follow-up questions
<i>What will be the same in each of the beakers (controls)?</i>	Yeast, sugar, water.	<i>What are the components that we are not investigating as possible causes?</i>
<i>What will be different in each of the beakers (independent variable)?</i>	Temperature.	<i>Which variable do we think causes a change in matter and energy in the zombie fire system?</i>
<i>How can we decide what temperature the beakers should be? What will help us answer our questions about the zombie fire system?</i>	We should have something cold, like permafrost. We should have something warmer than the permafrost because it is warming up.	<i>What has the peat in the zombie fire system been like in the past?</i> <i>What is happening in the zombie fire system that is causing a change?</i>

Discuss data collection in small groups. Display **slide M**. Read through Part 3 of *Decomposition Investigation Planning* as a class and show students the materials you will provide for measuring carbon dioxide output. The easiest data collection option is to estimate the output of carbon dioxide by measuring the height of foam produced in each beaker every 2 minutes. As students discuss the questions in groups, ask them to record their answers on their handout.

ALTERNATE ACTIVITY

If you have additional supplies available and/or want to support students in selecting tools to collect data (SEP 3), such as carbon dioxide probes, flasks, or bottles covered with balloons or other methods of capturing carbon dioxide gas, offer students these options here and alter *Decomposition Investigation Planning* and **slide M** as needed. See *Decomposition Investigation Preparation* for additional guidance.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

In middle school, students should have had opportunities to identify controls in investigations. If this element of the practice is unfamiliar to students, take time construct definitions to add to Personal Glossaries.

* ATTENDING TO EQUITY

Supporting Emergent Multilinguals: You may need to remind students what it means to provide a control condition, particularly if your students are multilingual. A control provides a standard against which other conditions can be compared in a scientific investigation, but it means something very different in everyday language. Highlighting how words can have different meanings in different contexts (i.e., in science versus everyday use) can provide emerging multilingual students the chance to discuss any alternative conceptions about the meaning of the word(s) and to draw upon their personal experiences.

7 • NAVIGATE

2 min

MATERIALS: science notebook



Students revise investigation plans individually. Display **slide N**. Give students time to reflect on the work they did in small groups today and revise their responses on *Decomposition Investigation Planning*. Collect *Decomposition Investigation Planning* from each student.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- **Energy and matter flow** from **sugar to yeast and carbon dioxide** in the investigation. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)
- **Data collection includes measuring carbon dioxide from the yeast after consuming sugar, conducting multiple trials and/or comparing one group's results to others for accuracy.** (SEP: 3.2; DCI: LS2.B.1, LS1.C.4)

What to do: Review *Decomposition Investigation Planning*, using *Decomposition Investigation Planning Key* as a guide. If students do not recognize that matter flows from sugar to carbon dioxide, spend some additional time as you navigate into day 2 reviewing this with students. Consider asking them to return to their model mapping and ask them to work with a partner to explain what they think happens to matter and energy in the system. Consider regrouping students on day 2 for the investigation based on their responses so that students who have had more practice with planning and carrying out investigations are grouped with students with less experience using the practice.

Building toward 3.A.1 Plan and carry out an investigation to produce evidence of **matter and energy flow in and out of systems under different conditions.** (SEP: 3.2; DCI: LS1.C.4; CCC: 5.2)

End of day 1

8 • NAVIGATE

3 min

MATERIALS: science notebook, *Decomposition Investigation Planning*

Revisit investigation plans. Display **slide O**. Return *Decomposition Investigation Planning* to each student. Use the prompts below to facilitate a whole-class discussion.

Suggested prompts	Sample student responses	Follow-up questions
<i>What question are we investigating today?</i>	How does a change in temperature affect the flow of matter and energy from sugar/plants to carbon dioxide/atmosphere by decomposers in the zombie fire system?	<i>What is the variable we are planning to change?</i> <i>What is the variable we are planning to measure?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>How does this help us make progress towards explaining why matter does not decompose in the permafrost?</i>	The sugar represents the peat, and our investigation will tell us how energy and matter flow at different temperatures.	<i>Look back at your model mapping. What did each component in the Decomposition Investigation map to in the zombie fire system?</i>
<i>What evidence will you collect?</i>	We will see how much carbon dioxide gets produced in each beaker.	

9 • REVIEW THE INVESTIGATION PLAN AND SAFETY CONSIDERATIONS

9 min

MATERIALS: Decomposition Investigation Data and Sensemaking

Review investigation plans. Say, *Based on your investigation plans from our last time, I put together a plan for the whole class to follow.* Distribute *Decomposition Investigation Data and Sensemaking* to each student. Display **slide P**. Organize students into the small groups based on your review of their work on day 1. Ask students to read the plan, marking it up, using whatever reading strategy is in place in your classroom, and ask any clarifying questions. Then ask them to discuss the questions on **slide Q**. Call on a few groups to share their thinking.

Suggested prompts	Sample student responses	Follow-up questions
<i>What will you measure and record in your data table to collect evidence to answer your questions about the flow of energy and matter?</i>	How much carbon dioxide is produced. Height of foam.	<i>What will happen when you put the yeast and sugar together?</i>
<i>How much data will your class collect?</i>	Each group has 3 beakers. Each group will collect data every two minutes for 20 minutes.	<i>Is it enough for each group to have 3 beakers? How do you know?</i>
<i>How will you know if your data is accurate?</i>	We can see if other groups get the same results as us.	<i>What would it mean if your results were really different from everyone else in your class?</i>



Review safety protocols and expectations. Display **slide R**. Say, *Responsible scientists are always concerned with safety and clean up. Let's review these Safety Considerations together.* Read the instructions from the slide. Add any information relevant to your classroom. Pause and ask students if there are any questions.

SAFETY PRECAUTIONS



- Wear safety goggles, non-latex aprons, and nitrile gloves during the setup, hands-on, and takedown segments of the investigation.
- Use caution pouring hot water from the hot plate to prevent risk of burning skin.
- Follow your teachers instructions for disposing of waste materials.
- Use caution when working with glassware, which can shatter if dropped and cut skin.
- Immediately pick up any items on the floor (e.g., spilled water) in the work zone so they do not become a slip/fall hazard.
- Ask your teacher where to safely place any equipment and materials upon completing the investigation.
- Wash your hands with soap and water immediately after completing this investigation.

10 · CARRY OUT DECOMPOSITION INVESTIGATION AND CLEAN-UP

25 min

MATERIALS: Decomposition Investigation, science notebook, *Decomposition Investigation Data and Sensemaking*

Carry out investigations. Display slide S. Direct students to collect their materials and begin their investigation. Circulate around the room to make sure that students follow proper safety protocols and that students have a plan for who will collect measurements and who will keep time.

Complete Making Sense questions. As students complete their investigations, direct them to the Making Sense questions on slide T and in *Decomposition Investigation Data and Sensemaking*. Ask them to discuss with their group and record their responses individually.

Clean up investigations. Say, *Once you are done collecting data, clean up your investigation*. Remind students of any necessary clean-up instructions specific to your classroom and display slide U.

11 · NAVIGATE

5 min

MATERIALS: *Decomposition Investigation Data and Sensemaking*



Compare results. Display slide V. Pair up groups of students. Ask them to share and compare the results of their investigations from *Decomposition Investigation Data and Sensemaking* looking for similarities and differences. Collect *Decomposition Investigation Data and Sensemaking* from each student.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Energy and matter flow from sugar to yeast and carbon dioxide in the investigation. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)
- Data collection includes measuring carbon dioxide from the yeast after consuming sugar, conducting multiple trials, and/or comparing one groups' results to others for accuracy. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4)

What to do: Collect *Decomposition Investigation Data and Sensemaking* from each student and provide feedback using *Decomposition Investigation Data and Sensemaking Key* for guidance.

Building toward 3.A.2 Plan and carry out an investigation to produce evidence of matter and energy flow in and out of systems under different conditions. (SEP: 3.2; DCI: LS1.C.4; CCC: 5.2)

End of day 2

12 · NAVIGATE

5 min

MATERIALS: *Decomposition Investigation Data and Sensemaking*, science notebook

Turn and Talk. Return *Decomposition Investigation Data and Sensemaking* to students. Display **slide W**. Ask students to turn and talk about what they figured out in the investigation on day 2 and what questions they still have. Call on a few pairs to share their thinking.

Suggested prompts	Sample student responses	Follow-up questions
<i>What did we figure out in our investigation in our last class?</i>	The yeast produced less carbon dioxide at lower temperatures. Decomposition was slower at lower temperatures. More of the matter and energy stayed in the sugar at colder temperatures. Less matter and energy were transferred to the yeast for it to grow when it was cold.	<i>What question did the investigation try to answer?</i> <i>What was the independent variable (cause)?</i> <i>What was the dependent variable (effect)?</i> <i>What happened to the matter and energy in the sugar?</i> <i>Where was the energy in the sugar transferred?</i>
<i>How does what we figured out relate to the peat in the zombie fire system?</i>	Decomposition was slow because it was cold in the permafrost. The decomposers in the peat did not eat as much plant matter, so the energy and matter stayed as peat instead of going to carbon dioxide in the atmosphere.	<i>What happens to the amount of energy and matter transferred at different temperatures?</i> <i>Under what conditions does more of the matter and energy stay where it started out?</i> <i>Under what conditions does more of the matter and energy flow to the atmosphere?</i>
<i>What questions do we still have?</i>	What else gets made that we cannot see? Is there only carbon dioxide made?	<i>What did you see in the burning in Lesson 2? Were there other products?</i> <i>Could we see evidence of all the matter and energy flow in our investigation? What can we not account for?</i>

ADDITIONAL GUIDANCE

Students will have ideas about temperature and energy from their everyday and prior school experiences. In middle school, students may have developed understanding of the following ideas:

- *Gases and liquids are made of molecules or interim atoms that are moving about relative to each other.* (MS PS1.B)
- *In a liquid, molecules are constantly in contact with others.* (MS PS1.A)
- *The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule.* (MS PS3.A)

Support them in considering how the temperature of the system affects the kinetic energy of the molecules and how that kinetic energy could impact the rate of reaction. Students will further develop these ideas in *OpenSciEd Chemistry*.

13 · SMALL-GROUP WORK USING MOLECULE CARDS TO REPRESENT MATTER AND ENERGY FLOW

13 min

MATERIALS: science notebook, *Decomposition Investigation Data and Sensemaking*, *Sensemaking: Matter Energy Cards*, *Matter Energy Cards*, 3x3 sticky notes

Introduce a small-group investigation with matter and energy cards. Say, *I heard you say that you still have some questions about the energy and matter that flow during this process and that there are parts of the system that we could not see in our investigation. I have some molecule cards for you to work with to help make sense of these unseen pieces.* Display **slide X**. Explain to students that you will give each group a set of cards and their job is to organize the cards to explain the flow of energy and matter in the zombie fire system using evidence from *Decomposition Investigation Data and Sensemaking*. Distribute *Matter Energy Cards* to each group.* As small groups organize their cards, circulate around the room and prompt students with questions such as:

- What form did the energy and matter start out as?
- Was any additional energy added to the system?
- What happened to the energy and matter when it was consumed by a decomposer?
- Where did the water and oxygen come from?
- How did temperature affect the flow of energy and matter?

ADDITIONAL GUIDANCE

As students organize their cards, they may use terms such as **chemical reaction**, and **bonds**. Many students will have worked with these definitions in middle school. (e.g., MS LC1.C, MS PS3.D, MS PS1.B). Some students may need additional support building understanding of these middle school grade band ideas. If this is the case, when students use the molecule cards and describe the reaction, take time to review and support students in adding definitions for terms such as *bonds* (*connections between atoms that form molecules*) and *chemical reactions* (*process by which bonds in molecules are rearranged and energy is transferred*). Pause to give students time to add definition(s) to their Personal Glossaries.

Individual and small-group sensemaking. After students have had a chance to organize their cards, distribute *Sensemaking: Matter Energy Cards* to each student and ask them to discuss with their small group and individually record their answers. *

* ATTENDING TO EQUITY

Differentiation: *Matter Energy Cards* contains enough cards that students could model what happened in each beaker and relate it to the zombie fire system at different time periods. Students who need additional support should start out with just one card of each type to model the general flow of energy and matter in the system. Students who have already demonstrated an understanding of the flow of energy and matter should model how the flow of energy and matter was different in each of the three beakers showing more or less glucose or carbon dioxide in each one. Challenge high-interest students to balance the flow of inputs and outputs with the correct number of cards to account for the number of atoms that flow through the system.

* ATTENDING TO EQUITY

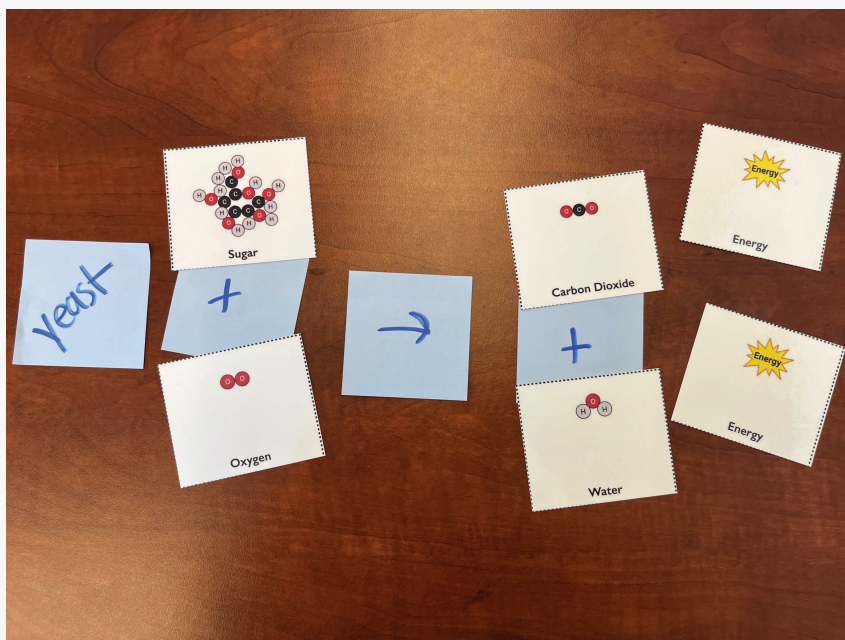
Differentiation: Challenge students who have already met the standard to balance the flow of matter from start to finish in cellular respiration. Let them know that glucose is $C_6H_{12}O_6$ and ask them to determine how many oxygen, carbon dioxide, and water molecules must be part of the process so that all matter is conserved.

14 · BUILDING UNDERSTANDINGS DISCUSSION ABOUT MATTER AND ENERGY FLOW USING THE MOLECULE CARDS

12 min

MATERIALS: science notebook

Facilitate a Building Understandings Discussion. Say, *You all did some great work using your molecule cards to represent some of the things we may not have been able to see with our eyes during the Decomposition Investigation. Let's take a few moments to make sense as a class of what you figured out with your group. Display slide Y. Call on a few groups to explain how they used the cards to make sense of the flow of energy and matter. Record a representation on the whiteboard or other public space that represents an agreed-on representation of the cards. A sample representation is shown below.*



Illustrations created by OpenSciEd in BioRender

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

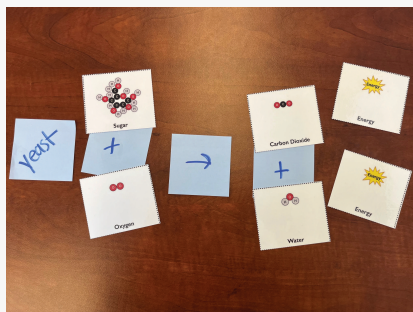
A Building Understandings Discussion is a useful kind of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and claims and to push them to support their conclusions and claims with evidence. Helpful prompts during this kind of discussion include:

- What can we conclude?
- How did you arrive at that conclusion?
- What's your evidence?
- Does any group have evidence to support Group A's claim?
- What data do we have that challenges Group B's claim?

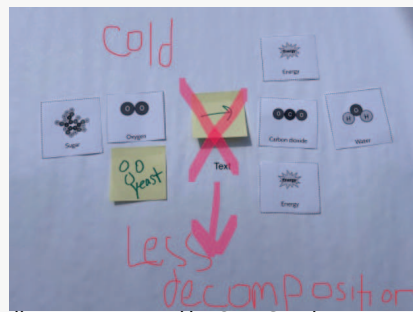
Then call on a few groups to share their responses to the remaining questions on *Sensemaking: Matter Energy Cards*. Use the prompts below to guide the rest of the discussion.*

Suggested prompts	Sample student responses	Follow-up questions
<i>How did your group represent the chemical reaction?</i>	Answers will vary and may look like the example images following this discussion.	<i>How have you represented chemical reactions in the past?</i> <i>How do you know which molecules are reactants and which are products?</i>

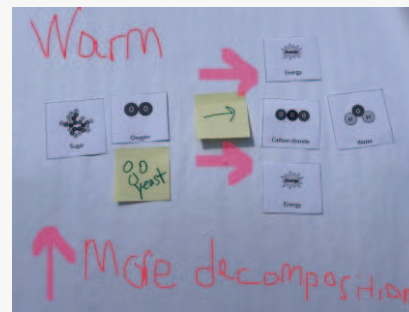
Suggested prompts	Sample student responses	Follow-up questions
<i>How does temperature affect reaction rate (how fast the reactants turn into products)?</i>	It was slower at lower temperatures. At low temperatures, more of the energy and matter stayed as reactants. There was less carbon dioxide at cooler temperatures, so the reaction was slower/not as much.	<i>What did you figure out in your Decomposition Investigation?</i> <i>How does thermal energy affect the kinetic energy/movement of molecules?</i>
<i>How does this help us explain the matter and energy in the peat in the zombie fire system?</i>	When it is cold, more of the energy and matter stays in the peat. Decomposition is slow when it is cold. The chemical reactions of the decomposers are slower when it is cold.	<i>What evidence do you have from your investigation?</i> <i>What is happening that is slower?</i> <i>What is the role of the decomposers?</i>
<i>What other factors might affect the rate of reaction in the zombie fire system and contribute to the energy and matter staying in the peat?</i>	Oxygen. How much sugar/matter there is. The peat formed under water, so maybe the conditions are different than in air.	<i>How can the reaction help us think about what else could change how fast decomposition happens?</i> <i>What did we figure out about the formation of peat that can help us here?</i>



Illustrations created by OpenSciEd in BioRender



Illustrations created by OpenSciEd in BioRender



Illustrations created by OpenSciEd in BioRender

KEY IDEAS

Purpose of this discussion: To build understanding about how temperature affects the rate at which decomposers use cellular respiration to rearrange molecules and release energy and to relate that to what is happening in the zombie fire system.

Listen for these ideas:

- Cold temperatures decrease the rate of decomposition.
- In the peat/permafrost, organic matter decomposes slowly because it has been in the permafrost, where there are lower temperatures.
- Since the peat decomposes so slowly, the carbon (matter/energy) stays in the peat and does not go to the atmosphere as carbon dioxide.

Update Personal Glossaries. Display **slide Z**. Let students know that they have explained a process called *cellular respiration*. Provide students with an opportunity to share their ideas for what to include in their definitions and give students an opportunity to record the definition in their Personal Glossaries.

ADDITIONAL GUIDANCE

Cellular respiration is part of the NGSS middle school grade band as described in MS PS3.D: *Cellular respiration in plants and animals involves chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.* While some students may be familiar with these ideas and can build on them, cellular respiration may be a new idea for others. Work together to come to a consensus on a common definition of *cellular respiration*, such as *the process of converting energy and matter in food into usable energy and other products.*

15 · SMALL-GROUP SENSEMAKING ABOUT OXYGEN AND CELLULAR RESPIRATION

10 min

MATERIALS: science notebook, *Oxygen and Decomposition*

Turn and talk about additional factors that affect reaction rate. Say, *We have made some major progress on answering our lesson question. You also brought up some factors that, in addition to temperature, could affect reaction rate of cellular respiration by decomposers in the zombie fire system.* Display **slide AA ***. Remind students about the peat formation process and ask students to turn and talk with a partner about factors that could have affected cellular respiration during peat formation in the zombie fire system. Circulate around the room and prompt students with questions such as:

- How were conditions different where the plants originally died?
- How might oxygen affect how much decomposition took place in the zombie fire system?

Listen for students to recognize that there is less oxygen under water and that the cellular respiration equation has oxygen in it so without it probably would not happen as much.

Review scientific data. Display **slide BB** and explain to students that you have some data from scientists who were interested in finding out more about how decomposition is affected by oxygen in places where plant matter is underwater, like it could be in peat in the thawing permafrost. They put decomposers and plant matter underwater with different amounts of oxygen and measured how the percentage of plant material changed over time. Their results are found on **slide CC**.

Individual and small-group sensemaking. Distribute *Oxygen and Decomposition* to each student. Provide individual think time and then organize students into small groups of 3-5. Ask them to discuss and record their responses to the question on **slide DD** in their science notebooks.

**ADDITIONAL
GUIDANCE**

In this activity, students are briefly introduced to the idea that cellular respiration can happen in the absence of oxygen. Students who demonstrate proficiency early in the lesson with ideas related to the flow of energy and matter through cellular respiration may benefit from comparing and contrasting the equations for fermentation (anaerobic respiration) and aerobic cellular respiration. They should recognize that single-celled decomposers such as yeast can live without oxygen; however, when oxygen is not present, more energy and matter stay in the peat. Encourage them to record definitions for anaerobic and aerobic in their Personal Glossaries.

16 · NAVIGATE: EXIT TICKET

5 min

MATERIALS: science notebook



Exit ticket. Display slide EE. Ask students to answer the question on the slide on a half sheet of loose-leaf paper from their science notebooks. The image represents decomposition via cellular respiration, resulting in soil, peat, or no change. They should number their exit tickets with 1, 2, 3, and 4 and select A, B, or C for each number. Collect an exit ticket from each student.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment::

- The highest rate of **cellular respiration/decomposition** would be represented by scenario A, where the greatest amount of **matter is converted from plants to the atmosphere and the greatest amount of energy is transferred** to the decomposers. (DCI: LS2.B.1, LS1.C.4; CCC: 5.2)
- In the future, if **temperatures continue to rise** and more peat is exposed to oxygen due to melting permafrost, the rate of **cellular respiration /decomposition** will increase. (DCI: LS2.B.1, LS1.C.4; CCC: 5.2)
- **Explanations** that include ideas that support the **increased/decreased flow of energy/matter** through **cellular respiration/decomposition**. (SEP: 6.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)

What to do: Use student exit tickets to determine which students need additional support developing their ideas about decomposition and the role of temperature and oxygen in the rate of cellular respiration/flow of energy and matter in the zombie fire system. Sort student responses into at least three piles, such as:

1. Students who got all items correct and whose explanations support their choice.
2. Students who got some items correct and and/or whose explanations may not fully support their choice.
3. Students who got most items incorrect and/or whose explanations may not fully support their choice.

The best choices for each item are as follows: 1. A; 2.C; 3. A; 4.A.

At the beginning of day 4, organize students into pairs of students who expressed similar ideas and prompt them with the following. The number of the question below corresponds to the grouping above:

1. What happens to the energy and matter in peat as the Arctic warms up?
2. How do energy and matter flow during cellular respiration?
3. How does decomposition work? What reaction happens during decomposition?

Building 3.B.1 Construct an explanation for factors that affect **cellular respiration**, resulting in changes in **the flow of matter and energy** in the zombie fire system. (SEP: 6.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)

End of day 3

17 · NAVIGATE

5 min

MATERIALS: science notebook

Turn and talk about what we figured out in the last class. Display slide FF. Pair students based on their exit tickets from the previous class. Support students in each of the categories with the prompts similar to those in the assessment guidance at the end of day 3.

18 · CONSENSUS DISCUSSION ABOUT CELLULAR RESPIRATION IN THE ZOMBIE FIRE SYSTEM

10 min

MATERIALS: science notebook, *Decomposition Investigation Data and Sensemaking*, chart paper, chart paper markers

Consensus discussion. Ask students to bring their science notebooks and form a Scientists Circle. Let students know that after figuring so much out, the class is ready to come to consensus on their ideas. Use the prompts below and on **slide GG** as a guide. *

* STRATEGIES FOR THIS CONSENSUS DISCUSSION

A Consensus Discussion is different from other kinds of discussions because the purpose of the discussion is to converge on one or more ideas that the whole class agrees upon. In this discussion, your classroom community is pressing toward a common (class-level) explanation, model, or model representation. During this work, the class resolves disagreements where possible. Your role is to help students see where they agree and where they still disagree. Helpful prompts include:

- What ideas are we in agreement about?
- Would anyone have put this point a different way?
- Who feels like their idea is not quite represented here?
- Are there still places where we disagree? Can we clarify these?

Suggested prompts	Sample student responses	Follow-up questions
<i>What did we figure out about why there is so much matter and energy in the peat in the zombie fire system?</i>	There is a lot of plant matter that has not decomposed. It is cold, and there is not a lot of oxygen, so it has not decomposed.	<i>What evidence did we collect about decomposition?</i>
<i>What happens to plant matter when it decomposes?</i>	Through cellular respiration, the matter reacts with oxygen and is converted into carbon dioxide and water plus energy.	<i>What happens to matter and energy during decomposition?</i>
<i>When decomposition and cellular respiration are slow, what happens to the matter and energy?</i>	The matter and energy stay in the peat.	<i>What is the chemical reaction that happens during decomposition/cellular respiration?</i> <i>What conditions slow down the rate of decomposition/cellular respiration?</i>
<i>What do these ideas about energy and matter have to do with zombie fires?</i>	It is getting warmer, and the permafrost is melting. All the carbon in the peat is fuel for the fires. There is a lot of matter and energy in the peat that can be a fuel for fire when it gets dried out.	<i>What do we know about how the Arctic is changing?</i> <i>What will happen to all the energy and matter in the peat?</i>

KEY IDEAS

Purpose of this discussion: For students to come to consensus on the idea that cold temperature and lack of oxygen have contributed to less decomposition of plant matter in the zombie fire system, leading to a lot of matter and energy in the peat in the permafrost.

Listen for these ideas:

- Matter and energy have stayed in the peat due to less decomposition.
- Low temperature and low oxygen slow down cellular respiration.
- Cellular respiration is where oxygen reacts with sugar to release energy, carbon dioxide, and water.
- Over time in the cold Arctic, the matter and energy have stayed in the peat.
- If it warms up, the permafrost will melt, and all the energy and matter in peat may be fuel for fire.

Update Personal Glossaries. Display **slide HH**. Provide students with an opportunity to co-construct the definition of a new word, *carbon sink*. Say, *You all have just explained an idea, that the peat is a place with a lot of energy and matter that is staying put. Scientists call this a carbon sink.*

ADDITIONAL GUIDANCE

During the discussion, students will describe how low rates of decomposition in the zombie fire system lead to a large amount of matter and energy being stored in the peat (that could be released when it burns). Work together as a class to co-construct a definition of the term *carbon sink*. For example: *A carbon sink is a large store of carbon (energy/matter) that is keeping it out of the atmosphere.* Students may visualize a sink in their home filling up with water equating to the peat system filling up with carbon.

ADDITIONAL GUIDANCE

If students are motivated to go beyond the standards in this lesson, an optional reading *Frozen in Time* is available to extend their thinking about decomposition in peat that supports students in understanding other factors that contribute to peat being an effective carbon sink, such as pH.

19 · REVISE CLASS CONSENSUS MODEL

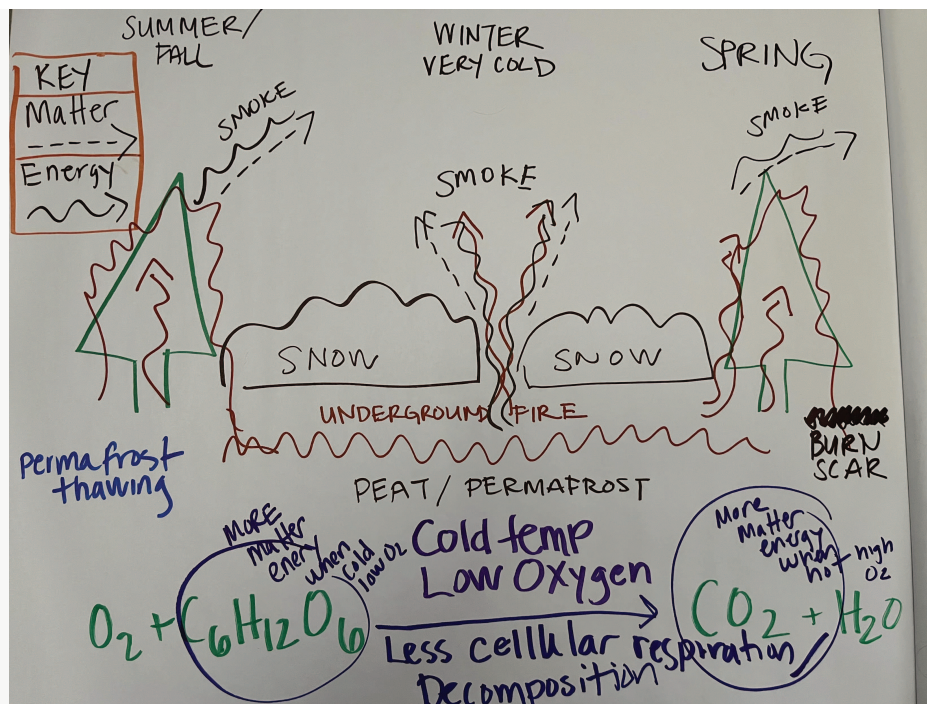
10 min

MATERIALS: science notebook

Revise class consensus model. Display **slide II**. Direct student attention to the class consensus model. Ask students to turn and talk to a partner about how they think the class should update the consensus model based on the ideas the class has figured out today. Call on a few pairs to share their thinking. Support students to build on each other's ideas with prompts such as, *Can anyone else add to what ____ said? What additional pieces are missing that we still need to add to our model?* As the class comes to consensus, add their ideas to the model. Listen for students to add:

- Cellular respiration and decomposition occurs at lower rates at colder temperatures, resulting in a great deal of matter and energy in the peat in the zombie fire system.
- Warming temperatures increase the rate of cellular respiration for decomposers, resulting in more matter and energy from the peat being used by decomposers and more carbon dioxide flowing into the atmosphere.

See a possible example of the model co-constructed by the class below:



20 · CONSTRUCT EXPLANATIONS FOR MATTER AND ENERGY IN THE ZOMBIE FIRE SYSTEM

15 min

MATERIALS: Peat/Permafrost Explanation, Peat/Permafrost Explanation Feedback Guidance



Construct an explanation about why there is so much matter and energy in the zombie fire system. Display slide JJ. Distribute *Peat/Permafrost Explanation* to each student. Describe how to use the questions and sentence starters as support. Collect the explanation from each student.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: See *Peat/Permafrost Explanation Feedback Guidance* for sample responses.

What to do: Collect *Peat/Permafrost Explanation* from each student and use *Peat/Permafrost Explanation Feedback Guidance* to evaluate responses. Provide students with an opportunity to revise and respond to your comments on *Peat/Permafrost Explanation Feedback Guidance* by rewriting their explanation before they use this explanation in Lesson 6.

Building 3.B.2 Construct an explanation for factors that affect cellular respiration, resulting in changes in the flow of matter and energy in the zombie fire system. (SEP: 6.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)

MATERIALS: None

Stop and Jot new questions. Display slide KK. Ask students to stop and jot any new questions they have in their science notebooks.

Additional Lesson 3 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.WHST.9-10.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

Students use evidence from their investigations to write explanations about the flow of energy and matter through decomposition and cellular respiration to explain why so much peat remains in the environment.

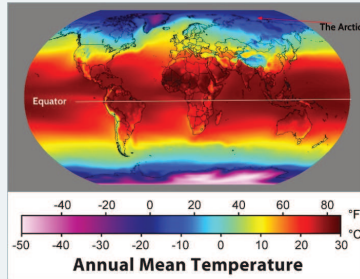
LESSON 4: How did so much plant energy and matter get into the peat in the zombie fire system?

PREVIOUS LESSON We decided to investigate why there is so much peat in the Arctic that has not decomposed. We planned and carried out an investigation using yeast as a model organism to generate evidence. We figured out that temperature affects the rate of decomposition/cellular respiration. We investigated the work of scientists who figured out that oxygen is also involved in the rate of decomposition/cellular respiration. We constructed an explanation based on evidence. We wondered how all that peat got there in the first place.

THIS LESSON

PROBLEMATIZING, INVESTIGATION

1 day



Robert A. Rohde for Global Warming Art, CC BY-SA 3.0

We consider what we have figured out and explore a puzzling idea: that there is a lot of energy and matter in the cold, snowy Arctic, where we do not expect it. We decide to investigate. We recall what we know about photosynthesis, relate photosynthesis to solar radiation, and read about Earth's conditions in the past and how they could have contributed to all of the energy and matter in the peat in the zombie fire system.

NEXT LESSON We will investigate how so much plant matter got to be stored as peat under the permafrost through readings and by planning and carrying out an investigation to generate evidence to support claims about the transfer of energy from the Sun to carbon-based molecules in plants. We will construct an oral explanation for how peat can contain large molecules.

BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



WHAT STUDENTS WILL DO

4.A Make a claim regarding changes in energy flow between the Sun and the Arctic and the potential of solar energy to be captured and stored in plants through photosynthesis. (SEP: 6.1; DCI: PS3.D.3; CCC: 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds through photosynthesis.
- As solar radiation in the Arctic decreased, many plants died, and peat and permafrost were formed.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Ask students to recall what they figured out last time and problematize the amount of peat in the Arctic.	A-B	
2	5 min		INITIAL IDEAS DISCUSSION ABOUT PHOTOSYNTHESIS Facilitate an Initial Ideas Discussion about the flow of energy and matter through plants.	C-D	
3	10 min		PHOTOSYNTHESIS CARD SORT Facilitate sensemaking about photosynthesis with a card sort.	E-F	<i>Matter Energy Cards</i> or cards from Lesson 3, 3 x 3 sticky notes
4	10 min		RETURN TO PLANT GROWTH IN THE ARCTIC Facilitate a whole-class discussion about photosynthesis and solar energy and temperature in the Arctic.	G-H	
5	10 min		GEOLOGIC TIME READING Facilitate the exploration of photosynthesis in the Arctic with a reading and whole-class discussion.	J-L	<i>Geologic Time</i>
6	5 min		NAVIGATE Facilitate completion of an Electronic Exit Ticket.	M	<i>Fires Progress Tracker</i> , https://docs.google.com/forms/d/174jIzIx_-iElbRcNKnhTv4SOfBpRT3e7c2lqLfyWJal/copy

End of day 1

Lesson 4 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Geologic Time</i> <i>Fires Progress Tracker</i> https://docs.google.com/forms/d/174jlzlx_-iElbRcNKhTv4SOfBpRT3e7c2lqLfyWJal/copy	<i>Matter Energy Cards</i> or cards from Lesson 3 3 x 3 sticky notes	

Materials preparation (30 minutes)

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

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

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

Be sure your Community Agreements are visible for reference during this lesson.

Make a local copy of the Electronic Exit Ticket https://docs.google.com/forms/d/174jlzlx_-iElbRcNKhTv4SOfBpRT3e7c2lqLfyWJal/copy so the form is accessible to your students. See *Exit Ticket Guidance* for additional guidance.

The *Matter Energy Cards* are the same cards used in Lesson 3 and can be reused.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students explore how so much plant material came to be in the Arctic in the form of peat.

They develop the disciplinary core idea HS-PS3.D, *The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis*, by building on ideas they should have from middle school such as:

- MS PS.3D *The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen.*
- MS LS1.C *Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.*

Students build on their middle school use of the practice *constructing explanations*, where they should have explained relationships between variables, as they make claims about the relationship between solar radiation (independent) and photosynthesis (dependent) in the zombie fire system.

Students continue to develop their use of the crosscutting concept *energy and matter* and use the element *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*, as they have in previous lessons in this unit.

In this lesson, students will co-construct a definition for *photosynthesis* and encounter the definition of *tilt*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

This lesson is designed to elicit and review middle school-level understanding of photosynthesis and build on those understandings to explain the unit phenomenon. The specifics of the light-dependent and -independent reactions along with bond formation, breaking, and rearrangement are beyond the scope of the standards targeted in the lesson. Lesson 5 will explore photosynthesis in greater depth and chemical reactions will be further explored in OpenSciEd Chemistry.

If students need more support in their understanding of photosynthesis, the simulation <https://www.openscienced.org/Chloroplasts-and-Food> can support their development of a middle school understanding and prepare them to work with photosynthesis in this lesson.

Students will have an opportunity to engage with the relationship between Earth's orbit, tilt, and shifts in climate in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

5 min

MATERIALS: science notebook

Review what we figured out last class. Display **slide A**. Ask students to turn and talk to a classmate to discuss what we figured out last class and what we decided to work on next. Call on a few pairs of students to share their thoughts. Listen for students to summarize the ideas they figured out in Lesson 3, such as:

- Low temperatures slow down decomposition/cellular respiration and keep the energy and matter in the peat.
- Warming temperatures can speed up decomposition/cellular respiration, and more of the energy and matter end up in the atmosphere as carbon dioxide.

Problemalyze the presence of peat in the Arctic. Say, *We figured out why the energy and matter have stayed as peat in the zombie fire system for a long time, but I am confused. The Arctic is so cold and snowy. How did all that plant matter get there in the first place?* Display **slide B** and give students a few minutes to stop and jot the answers to the question on the slide in their science notebooks. Call on a few students to share their ideas. Use the prompts below as a guide:

Suggested prompt	Sample student response
<i>How did all that plant matter end up in the cold and snowy Arctic?</i>	Maybe it took a long time to get there and build up over many years. The conditions there could have been different in the past.
<i>Where on Earth is there a lot of plant matter?</i>	Where there is a lot of sun. The equator. Places in the south.
<i>What happens in those places that causes a lot of matter to be stored in plants?</i>	They are hot and sunny. They have a lot of water, not a desert. They have a lot of photosynthesis.

2 · INITIAL IDEAS DISCUSSION ABOUT PHOTOSYNTHESIS

5 min

MATERIALS: science notebook

Turn and talk about photosynthesis. Say, *I heard you all mention that there are conditions necessary for there to be a lot of plant matter in a particular place.* Ask students to turn and talk about the question on **slide C**.

Initial Ideas Discussion about photosynthesis. Then facilitate an Initial Ideas Discussion * to elicit student ideas about photosynthesis. Use the prompts below as a guide.

* STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

Reasons for eliciting students' initial ideas include:

Suggested prompt	Sample student response
How do energy and matter flow into plants?	They take in light, water, and carbon dioxide. They turn carbon dioxide into sugar/food.
How is plant matter made?	Plants use photosynthesis to make more plant matter.
How do energy and matter flow out plants?	Something eats it. They put oxygen into the air.

- To get students' prior knowledge and experiences on the table.
- To provide a supportive opportunity for students to make sense of what may not be fully formed ideas (either their own ideas or those of others).
- To help students realize that there are gaps in our understanding to promote curiosity and consider what we could do next to figure something out.

KEY IDEAS

Purpose of this discussion: To elicit students' prior understanding about photosynthesis.

Listen for these ideas:

- Plants take in carbon dioxide and give off oxygen through photosynthesis.
- Energy from the Sun is necessary for this process.
- Plants make food during photosynthesis in the form of sugar.
- Water is involved in photosynthesis.

Update Personal Glossaries. Display **slide D**. Say, *I heard you describe a lot of the features of the process called photosynthesis. Let's pause to come to a consensus on a definition for our Personal Glossaries.*

ADDITIONAL GUIDANCE

By this point, students will likely have mentioned photosynthesis. When this happens, pause to add a definition in the Personal Glossaries. Student understanding of photosynthesis may be more aligned with middle school, which includes the idea that 1) *the chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen (MS PS3.D)* and 2) *plants use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which releases oxygen. These sugars can be used immediately or stored for growth or later use (MS LS1.C)*. Remind them to leave space to add to this definition as they further develop these ideas.

If students need additional support with a middle school understanding of photosynthesis, provide them with access to a device that can support the simulation <https://www.openscienced.org/Chloroplasts-and-Food>.

3 · PHOTOSYNTHESIS CARD SORT

10 min

MATERIALS: science notebook, *Matter Energy Cards* or cards from Lesson 3, 3 x 3 sticky notes

Photosynthesis card sort. Say, *You all already know a lot about energy and matter flow through photosynthesis. To support your thinking, I am going to distribute Matter Energy Cards to each group.* * Give students a few minutes to organize their cards in a way that explains their ideas about the flow of energy and matter in photosynthesis. Display **slide E**. Students may also benefit from sticky notes or small whiteboards to draw or write additional ideas on if available.

* ATTENDING TO EQUITY

Building classroom culture: It is important to organize activities in ways that create opportunities for students to engage in meaningful, accountable talk by emphasizing socially safe activity structures

ADDITIONAL GUIDANCE

Challenge students to use the card sort to balance the photosynthesis equation in the same way that they balanced the cellular respiration equation in Lesson 3.

Whole-class discussion. Call on a few groups to share how they organized the flow of energy and matter with the cards. Use the following prompts as a guide and make a representation of student ideas on the whiteboard or another public space. This may look something like the image on **slide F**.

(e.g., small-group or partner work before a whole-class discussion). This is especially beneficial to multilingual students. For this reason, partner talk or small-group talk should precede whole-group discussion whenever possible to give students an opportunity to share their ideas with one or two peers before going public with the whole class.

Suggested prompt	Sample student response
<i>What molecules did you think flow into photosynthesis?</i>	Carbon dioxide and water.
<i>What happens to those molecules during the process of photosynthesis?</i>	They get turned into sugar and oxygen.
<i>What does the Sun have to do with it?</i>	The Sun provides the energy to rearrange those molecules.
<i>What happens to the molecules that are made during photosynthesis?</i>	The plant uses them for food. Other animals eat them and use them for energy. Other organisms use the oxygen released.
<i>How does photosynthesis relate to cellular respiration and the decomposers we talked about in the zombie fire system?</i>	The decomposers eat the plants and use the oxygen to do cellular respiration. They put the carbon dioxide back into the atmosphere.

4 • RETURN TO PLANT GROWTH IN THE ARCTIC

10 min

MATERIALS: science notebook

Summarize what we know and what we still need to figure out. Say, *We have made sense of how energy and matter flow through photosynthesis, but we still have not figured out how there got to be so much plant matter in the Arctic. Can you think of times when the amount of matter and energy in plants has changed where you live or in a place you have visited?* Listen for students to share ideas about changing seasons, falling leaves, or plants dying. Ask, *How can we investigate this further?* Listen for ideas such as reading, watching a video, or analyzing data.

Share global radiation and photosynthesis data. Say, *I found some data that I think can help us.* Ask students to create a Notice and Wonder chart in their science notebooks. Display **slide G** and give them a minute to record their observations. Prompt students to make sense of the image by asking them to consider what the colors mean. Then display **slide H** and give them a minute to record their observations.

ADDITIONAL GUIDANCE

The image on **slide G** shows solar irradiance (the power per unit area received by the Sun as electromagnetic radiation) measured in kilowatts per square meter. Electromagnetic radiation is beyond the scope of this unit and will be addressed in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*. Students need only to relate the color scale to energy from the Sun.

The image on **slide H** shows the mean GPP (gross primary production) by latitude. Gross Primary Product (GPP) can be used as a measure of photosynthesis (PS) because it is a measure of the total amount of carbon-based molecules produced by plants in a given period of time. The more photosynthesis, the higher the GPP. Students should relate the color scale to the amount of photosynthesis.

Turn and Talk. Ask students to turn and talk to a partner about the data on the slides. For additional student support, distribute *Photosynthesis Data Images*. *

Facilitate a whole-class discussion. Use the prompts below and on **slide I** to facilitate a whole-class discussion about solar energy and temperature in the Arctic.

Suggested prompt	Sample student response
<i>What did you notice about the solar radiation data?</i>	The amount of solar radiation in the Arctic is really low compared to other places on Earth.
<i>What did you notice about the photosynthesis data?</i>	There is less photosynthesis in the Arctic and more near the equator.
<i>What is the relationship between solar radiation and photosynthesis? Which variable is the cause (independent), and which is the effect (dependent)?</i>	There is less photosynthesis when there is less solar radiation and vice versa. The solar radiation causes photosynthesis.
<i>Does this data help us explain why there is so much peat in the Arctic? Explain.</i>	No, not really. It seems like there should not be much plant matter there because there is not a lot of energy from the Sun or photosynthesis.

5 · GEOLOGIC TIME READING

10 min

MATERIALS: *Geologic Time*

Generate ideas about how to find out more about photosynthesis in the Arctic. Say, *We have some ideas about how solar radiation and photosynthesis are related across the globe, but this information has not helped us understand why there is so much matter and energy in the peat in the zombie fire system. How can we find out more?* Listen for suggestions such as conducting research with readings, videos, or data. Let students know that you have a reading that will help them build a further understanding of the plants in the zombie fire system.

Introduce a reading. Display **slide J**. Distribute *Geologic Time* to each student. Give students several minutes to read individually. Encourage them to annotate the reading using whatever literacy strategy is in place in your school/classroom.

Facilitate a small-group discussion. Organize students into small groups and ask them to answer the questions found on **slide K** in their science notebooks. Once students have had a chance to discuss and answer the questions, call on a few groups to share their thinking using the prompts below as a guide. If students have difficulty noticing the subtle difference in the tilt from the image in the reading, display **slide L**. **

Suggested prompt	Sample student response
<i>What factors could contribute to the quantity of carbon stored in the peat in the permafrost?</i>	It has become less tilted, which means there is less solar energy in the Arctic and it is colder. The solar energy is the direct sunlight that the plants use for photosynthesis. When there is more photosynthesis, more plant matter is produced.
<i>How have those factors changed over time?</i>	Eleven thousand years ago, when the plants grew that became the peat, there was more solar energy in the system because the tilt of the Earth was different. Since there was more solar energy, there was more energy to be converted into plants, which increased the amount of matter in the system. As the Earth's tilt decreased, there was less solar energy in the system to get converted to sugar through photosynthesis, so less matter was produced. Over time, it got colder, many plants died and formed peat, and the permafrost froze over or around it all.
<i>What does this have to do with today and how much energy and matter are in the peat in the zombie fire system?</i>	All of the matter and energy from the past where there was more solar radiation is trapped in the permafrost as peat.

* ATTENDING TO EQUITY

Students will encounter the definition for *tilt* in the context of the Earth in the reading. Pause and give students a moment to add this definition to their Personal Glossaries if it is a new definition or if it is being used in a new way. Encourage EMLs to use pictures, symbols, and other associated words to help add to their understanding of the word.

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

The purpose of this discussion is to support students in understanding how changes of energy and matter that flow into and out of the system (CCC) relate to photosynthesis and the amount of plant matter in the zombie fire system (DCI) by evaluating the relationship between the amount of solar radiation available and the amount of photosynthesis. The greater the Earth's tilt, the greater the amount of solar radiation available. The greater the amount of solar radiation, the greater the amount of photosynthesis.

6 · NAVIGATE

5 min



Complete the Electronic Exit Ticket. Display slide M. Say, *We figured out some pretty important things about this system and how the energy available has changed over time. Let's take a moment to record our ideas.*

Have students complete https://docs.google.com/forms/d/174jlzlx_-iElbRcNKnhTv4SOfBpRT3e7c2lqLfYWJal/copy. Encourage students to use their notes and reading to help them answer the questions on the Electronic Exit Ticket. See *Exit Ticket Guidance* for instructions on how to make the Electronic Exit Ticket.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *L4 Electronic Exit Ticket Key* for guidance.

What to do: See *L4 Electronic Exit Ticket Key* for guidance.

Building toward 4.A. Make a claim regarding changes in energy flow between the Sun and the Arctic and the potential of solar energy to be captured and stored in plants through photosynthesis. (SEP: 6.1; DCI: PS3.D.3; CCC: 5.2)

Additional Lesson 4 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.WHST.9-10.9 Draw evidence from informational texts to support analysis, reflection, and research.

Students use images and a reading as informational text to analyze and reflect on how changes in the Earth's tilt could affect the amount of solar radiation received in the Arctic.

LESSON 5: Could changes in the Earth's tilt cause more energy and matter to be stored in plants?

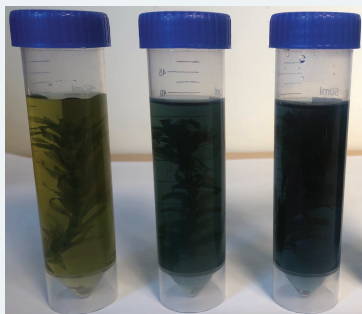
PREVIOUS LESSON

We explored a puzzling idea: that there is a lot of energy and matter in the cold, snowy Arctic, where we do not expect it. We decided to investigate. We recalled what we know about photosynthesis, related photosynthesis to solar radiation, and read about Earth's conditions in the past and how they could have contributed to all of the energy and matter in the peat in the zombie fire system.

THIS LESSON

INVESTIGATION

3 days



We decide to investigate how so much plant matter got to be stored as peat under the permafrost. We read about the formation of peat thousands of years ago and the conditions on Earth at that time. We plan and carry out an investigation to generate evidence to support our claims about the transfer of energy from the Sun to carbon-based molecules in plants. We construct an oral explanation for how peat can contain large molecules.

NEXT LESSON

We will develop our class consensus model and put together all of the evidence we have collected throughout the first half of the unit to construct an explanation for zombie fires. We will take stock of our progress and determine next steps.

BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ESS3-6, HS-ETS1-2



WHAT STUDENTS WILL DO

5.A Make a directional hypothesis to specify what happens to energy and matter flow through photosynthesis (dependent) when the amount of solar energy (independent) changes. (SEP: 3.5; DCI: LS1.C.1; CCC: 5.2)

5.B Plan and carry out an investigation, considering type, amount, and accuracy of data, to support explanations about changes in energy flow during photosynthesis under different conditions. (SEP: 3.2; DCI: LS1.C.1; CCC: 5.2)

5.C Apply scientific reasoning to link evidence to claims about how energy from the Sun drives the flow of matter from carbon dioxide in the atmosphere to sugar molecules assembled into larger molecules found in peat. (SEP: 6.4; DCI: LS1.C.2; CCC: 5.4)

WHAT STUDENTS WILL FIGURE OUT

- Through photosynthesis, plants convert carbon dioxide and water into sugar and oxygen.
- More solar energy means more carbon dioxide is captured and stored by plants as sugar and releases oxygen.
- Plants convert excess sugar into larger carbon-based molecules, such as starch.
- Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds.
- As solar radiation in the Arctic decreased, many plants died, and peat and permafrost were formed.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Ask students to discuss exit ticket responses from the previous lesson.	A-C	
2	10 min		INTRODUCE THE DIRECTIONAL HYPOTHESIS Support students' investigation ideas.	D-E	<i>Hypothesis Development</i> , whiteboard, dry erase markers, Community Agreements
3	13 min		PLAN AN INVESTIGATION, INDIVIDUAL Support students in planning an investigation.	F-H	<i>Tilt Investigation Planning</i> , <i>Peer Feedback Protocol</i>
4	14 min		PLAN AN INVESTIGATION, WHOLE CLASS Share ideas and plan for an investigation.	I	<i>Tilt Investigation Planning</i> , <i>Peer Feedback Protocol</i> , <i>Tilt Investigation Instructions</i> , whiteboard, dry erase markers
5	3 min		NAVIGATE Share evidence needed from investigation plans.	J	
End of day 1					
6	5 min		NAVIGATE Review investigation plans.	K	
7	8 min		MAP INVESTIGATION TO ZOMBIE FIRE SYSTEM Support students in mapping the investigation set-up to the phenomenon they are investigating.	L	
8	17 min		CARRY OUT INVESTIGATIONS Support small groups in carrying out investigation plans.	M-O	<i>Tilt Investigation Instructions</i> , Earth's Tilt Investigation
9	5 min		MAKE PREDICTIONS Support small groups in carrying out investigation plans.	P	<i>Tilt Investigation Instructions</i>
10	10 min		NAVIGATE Share predictions about investigations.	Q	
End of day 2					
11	2 min		NAVIGATE Revisit predictions.	R	
12	16 min		DATA COLLECTION AND CLEAN-UP Facilitate student data collection.	S-T	<i>Tilt Investigation Instructions</i>
13	8 min		MAKE SENSE OF INVESTIGATION DATA Guide small groups to compete Making Sense questions.	U	<i>Tilt: Making Sense</i>

Part	Duration		Summary	Slide	Materials
14	8 min		BUILDING UNDERSTANDINGS DISCUSSION Facilitate a Building Understandings Discussion about photosynthesis in the Arctic over time.	V-W	<i>Tilt: Making Sense</i>
15	8 min		INVESTIGATE STARCH Introduce a starch test to measure carbon stored.	X-AA	Energy and Matter Storage in Plants
16	8 min		CONSTRUCT AN EXPLANATION Guide students to construct explanations.	BB	
17	3 min		NAVIGATE: UPDATE PROGRESS TRACKERS Guide students to update Progress Trackers.	CC	<i>Fires Progress Tracker</i>

End of day 3

Lesson 5 • Materials List

	per student	per group	per class
Earth's Tilt Investigation materials	• safety goggles • non-latex apron • nitrile gloves	• 3 test tubes with airtight lids labeled A-C • 2 Elodea plants • BTB solution • 2 pieces of aluminum foil	• 3 clamp lights
Energy and Matter Storage in Plants materials		• Elodea from Earth's Tilt Investigation	• Petri dish or other leak proof shallow container • Scissors or forceps • Reagent grade iodine solution • 30 mL • Pipette • Hot plate • Heat-proof tweezers/forceps • Heat-proof tongs • Ethanol 95% laboratory grade • Heat-proof 1000 ml beaker • Heat-proof 250 mL glass flask • Safety goggles • Non-latex apron • Nitrile gloves • 500 mL water
Lesson materials	• science notebook • <i>Hypothesis Development</i> • <i>Tilt Investigation Planning</i> • <i>Peer Feedback Protocol</i> • <i>Tilt Investigation Instructions</i> • <i>Tilt: Making Sense</i> • <i>Fires Progress Tracker</i>		• whiteboard • dry erase markers • Community Agreements

Materials preparation (30 minutes)

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

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

Three-hole-punch all handouts so they can be added to student notebooks. Prepare whiteboard and dry erase markers or equivalent.

Print *Hypothesis Development* and cut in half.

Be sure your Community Agreements are visible for reference during this lesson.

Review *Investigation Preparation* prior to the lesson.

Part 1: Earth's Tilt

- **Group size:** Students work in groups of 4-5.

- **Setup:** Provide each group with: 3 test tubes with airtight lids, 1-2 Elodea plants, BTB solution. Students will set up the investigation on day 2 and will make sense of their results on day 3. Test tubes must be kept under a lamp overnight.

Part 2: Energy and Matter Storage in Plants (optional as demo, photos included in lesson)

- **Setup:** Iodine solution, scissors to take clippings of the Elodea plants, paper plates. You will need to set up a beaker of boiling water with a beaker of ethanol inside.
- **Notes for during the lab:** Place Elodea clippings in boiling water for 60 seconds and then in the ethanol for two minutes. Put the clippings on the paper plates and use the pipette to add 2-3 drops of iodine solution.
- **Safety:**
 - Wear indirect vented chemical splash goggles, a non-latex apron, and nitrile gloves during the setup, hands on, and takedown segments of the activity.
 - Wash your hands with soap and water immediately after completing this activity.
 - Never eat any items used in a lab activity.
 - Never taste any substance or chemical in the lab.
 - Use caution when working with glassware, which can shatter if dropped and cut skin.
 - Use caution when working with clamp lights - use only a GFCI protected electrical receptacle to power the lights and keep away from water sources.
 - Also, use caution when touching the light so as to prevent burning of the skin.
 - Immediately wipe up any spilled water off the floor to prevent slip/fall hazards.
 - Any electrical cords must be off the floor to prevent trip/fall hazards.
 - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemical used are required.
- **Disposal:**
 - Many species of Elodea are invasive, so be mindful that remnants of your plants do not get into local ecosystems. If Elodea is prohibited in your state, opt for the Elodea alternative provided by Carolina when ordering your kit.
 - Disposal should be in accordance with applicable regional, national, and local laws and regulations. Typically, Elodea can be safely disposed of by placing it in a plastic bag to freeze it for at least 72 hours before discarding the unopened bag in the trash.
 - Local regulations may be more stringent than regional or national requirements. These regulations can typically be found by performing a Google search using the search terms "Elodea disposal rules in [state]."
- **Storage:** No need to store anything once they have been used for data collection by all of the sections.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

By the end of Lesson 4, students suspect that a difference in the tilt of the Earth's axis might have created the conditions for many plants to grow in the Arctic in the past. In this lesson, they generate evidence to support their ideas.

Students continue to develop *planning and carrying out investigations* by using a new element where they make directional hypotheses. The lesson scaffolds the development of this element through the use of sentence starters. This builds on their use of the practice in Lesson 3 where they identified variables and considered types of data. In this lesson, they also focus on the kind, amount, and accuracy of the evidence they collect and are supported in the use of this practice by peer feedback.

Students continue to develop their use of *constructing explanations* and use a new element to apply scientific ideas and evidence to their claims in response to their hypotheses.

Students continue to build on the middle school ideas about photosynthesis elevated and developed with HS-PS3.D *The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis* and add a new understanding of HS-LS1 *The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make ~~amino acids and other~~ carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells.*

Students continue to develop and use elements of the crosscutting concept *energy and matter*, focusing on how energy from the Sun drives the conversion of solar radiation to chemical energy in plants and how changes to the amount of energy available affect the zombie fire system.

In this lesson, students will co-construct a definition for *chemical energy*. They will encounter the definition for *directional hypothesis*.

Where We Are NOT Going

Students will not be figuring out how bonds form, break, or are rearranged. They will develop a more complex understanding of chemical energy and chemical reactions in OpenSciEd Chemistry.

The pathways and molecules involved in the light-dependent and independent reactions of photosynthesis are beyond the scope of the NGSS high school grade band and are not necessary to explain our phenomenon. Further exploration of these components of photosynthesis can serve as an extension to extend learning for students who demonstrate mastery of the ideas in the high school grade band early in the lesson.

Students will not explore how smaller molecules are used to make amino acids, proteins, or DNA. They will explore these ideas in *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*.

If students need more support in their understanding of photosynthesis, the simulation <https://www.openscienced.org/Chloroplasts-and-Food> can support their development of a middle school understanding and prepare them to work with photosynthesis in this lesson.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

MATERIALS: science notebook

Navigate. Display **slide A**. Say, *We figured out some pretty important things about this system and how the solar energy available in the Arctic has changed over time. This may have affected how much matter and energy got stored in the peat in the zombie fire system due to photosynthesis. Let's take a moment to discuss what we figured out.* Ask students to turn and talk about the question on the slide.

Turn and talk about the Electronic Exit Ticket. Display **slide B**. Ask students to take turns sharing the claims they made in the last lesson and what evidence they used from the figures on the slide to support their claim about the relationship between solar radiation and photosynthesis. Call on a few pairs to share their thinking. Listen for students to recognize that greater amounts of solar energy are associated with higher levels of photosynthesis.

Review ideas about the Earth's tilt. Say, *Based on the data in the figures, we think there is less solar radiation in the Arctic and therefore less plant matter stored as carbon through photosynthesis.* Ask students to turn and talk about the question on **slide C**, *How is there so much energy and matter in the peat if the Arctic has less solar energy and photosynthesis?* Call on a few pairs to share. Listen for students to recall ideas related to differences in the Earth's tilt and how a greater tilt could increase solar radiation and energy/matter stored in plants through photosynthesis.

Use the following prompts to support students to dig deeper into their evidence and reasoning:

- *How could changes in the Earth's tilt connect to changes to matter and energy in the zombie fire system?*
- *What evidence from our readings or investigations supports your ideas?*
- *How did the change in tilt affect the available sunlight?*
- *How did the changes in available sunlight affect the amount of plant matter in the zombie fire system?*
- *How did changes in available sunlight affect the amount of energy stored in the peat in the zombie fire system?*

2 · INTRODUCE THE DIRECTIONAL HYPOTHESIS

10 min

MATERIALS: science notebook, *Hypothesis Development*, whiteboard, dry erase markers, Community Agreements

Introduce a directional hypothesis as an investigative tool. Say, *It sounds like you have a lot of great ideas about how changes in the Earth's tilt resulted in additional solar radiation in the Arctic being captured and stored as chemical energy in plant matter in the zombie fire system. Before we investigate this further, I want to introduce you to a tool called a directional hypothesis.*

Display **slide D**. Introduce the concept of a directional hypothesis, a proposed explanation for the relationship between two variables in a phenomenon. Pause to give students a moment to add *directional hypothesis* to their Personal Glossaries.* Invite students to turn and talk about how to phrase their ideas about solar energy and carbon storage as a directional hypothesis using the prompt on the slide, *What is the relationship between available sunlight and the amount of carbon plants store through photosynthesis?*



Small-group hypothesis development work. Once students have generated ideas about the relationship between the variables, distribute *Hypothesis Development* to each student and organize them into small groups to develop their directional hypotheses. Each student should individually record their thinking on the handout.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Students should have had an opportunity to frame hypotheses as they developed SEP 1 *asking questions and defining problems* in middle school. In high school, students build on framing hypotheses from scientific principles and observations to specify expected relationships between independent and dependent variables when planning and carrying out investigations.

* ATTENDING TO EQUITY

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Directional hypotheses (SEP: 3.5) that identify:

- Solar radiation/light energy as the independent variable. (SEP: 3.5; DCI: LS1.C.1; CCC: 5.2)
- Photosynthesis and carbon stored in plants as the dependent variable. (SEP: 3.5; DCI: LS1.C.1; CCC: 5.2)

What to do: Collect *Hypothesis Development* from each student. Check to make sure students correctly identify the variables and the direction of the relationship. For students who need support with either variables or relationships, check in with them while they are working individually and in small groups on investigation planning to support their thinking. If students do not correctly identify the dependent and independent variables, point them to the terms *cause* and *effect* to help them see the relationship. Use a prompt such as, *Which variable causes a change in the other?* If students do not choose the correct direction of the relationship, ask them to explain the relationship in pictures or words with prompts such as, *How is energy flowing in this system? What happens when there is a change in the amount of energy available?* Return *Hypothesis Development* while they work on investigation planning so they can recall their direction hypotheses.

Building toward 5.A Make a directional hypothesis to specify what happens to energy and matter flow through photosynthesis (dependent) when the amount of solar energy (independent) changes. (SEP: 3.5; DCI: LS1.C.1; CCC: 5.2)

Building classroom culture: Identifying a specific focal agreement to work on in concert with introducing the purpose of protocols, talk moves, and discourse strategies to support advancing that agreement serves two purposes. It can give students practice with new ways to interact with the members of their learning community, as well giving them experience using strategies that can help them engage in science and engineering practices more deeply over time.

Whole-class discussion of directional hypotheses. Display slide E. Paraphrase the proposed directional hypotheses you heard during small-group work. Say, *We have evidence that supports the relationship we named in our directional hypothesis from our reading, but how can we figure out if the change in light available due to tilt causes changes? Is it possible for us to generate our own evidence to support our claims? How can we do that?* Listen for student suggestions related to planning and carrying out an investigation to measure how differences in light energy, based on tilt, affect how much chemical energy plants store through photosynthesis.

Whole-group discussion about investigation ideas. Use the prompts below to guide a whole-class discussion about investigation ideas. Record these initial ideas for investigation on the whiteboard or other public space so students can use them when planning the investigation on their own in the next activity.

Suggested prompt	Sample student response
What does it look like if we are helping our learning community as we are choosing materials and planning investigations together? *	We should come to a consensus as a group about the materials we use. We should make sure everyone in the group has a chance to share their ideas or make suggestions. We should listen to everyone before we begin investigating. We could collaborate with other groups and share ideas with them.
It is really great to see all the different ways we help each other. It shows me that this is a learning community that is honoring their agreements and responsibilities to each other, in ways that are benefiting each of us at an individual level. Is there a Community Agreement that would help us most as we plan and carry out investigations? Why?	Accept all responses.

Suggested prompt	Sample student response
<i>What can we do to collect evidence that supports our claim that the more energy there is available from the Sun (based on the Earth's tilt), the more carbon plants will take in via photosynthesis?</i>	We can grow plants in different kinds or amounts of light and see if more light makes them grow more. We can give the plants more light and somehow see how much photosynthesis they do.
<i>What do you remember about our Lesson 2 investigation, where we burned peat, that can help us?</i>	We burned peat and used BTB to test for carbon dioxide. Maybe we can use BTB to help us track carbon dioxide.
<i>What do you remember about our Lesson 3 investigation, where we investigated decomposition with yeast, that can help us?</i>	We fed the yeast sugar and measured how much carbon dioxide the yeast put out. In photosynthesis, oxygen comes out. Maybe there is some way to measure that.

3 • PLAN AN INVESTIGATION, INDIVIDUAL

13 min

MATERIALS: *Tilt Investigation Planning, Peer Feedback Protocol*

Share information about available materials. Say, *I have some materials that we can use for our investigation.* Display **slide F** and show students the available supplies. Let them know that you have found a plant that they can use that lives in water that will give us an opportunity to use BTB in our investigation. Ask the class to recall what BTB was used for in Lesson 2. They should indicate that BTB turns from blue to yellow in the presence of carbon dioxide.



Provide individual planning time. Display **slide G**, distribute *Tilt Investigation Planning* to each student, and let them know that you have a tool to help them think about how to organize their ideas into a plan to collect evidence to support or refute their hypotheses. Provide students with time to work independently on their plans. As they work, circulate around the room and use shorthand to annotate their individual plans with feedback as described below and on the slide.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

Indications of plans that will generate evidence to test student claims, including:

- Varying amounts/intensity/direct light energy. (LS1.C.1; CCC; 5.2)
- A way to measure the flow of matter and energy from the Sun, the carbon dioxide, and water to the plant. (SEP: 3.2; LS1.C.1; CCC; 5.2)
- Plans to collect enough accurate data by compiling and comparing class data. (SEP: 3.2)

What to do: Circulate around the room to annotate students' individual investigation plans to provide feedback, starting with students whom you have not yet talked to or who are still building understandings of the focal SEP. Explain that you will use the following shorthand notes.

- A dot when you think the plan is on track.
- An arrow next to a part of the plan you think needs to be revisited or changed.
- A question mark next to any part of the investigation plan that is currently unclear.

Building toward 5.B.1 Plan and carry out an investigation, considering type, amount, and accuracy of data, to support explanations about changes in energy flow during photosynthesis under different conditions. (SEP: 3.2; DCI: LS1.C.1; CCC: 5.2)

Engage in peer feedback. Display slide H. Once every student has a draft of their plan, share *Peer Feedback Protocol* with them and give them time to review another classmate's investigation plan. Each student should review a peer's feedback and consider revisions to bring to the whole-class discussion.

4 • PLAN AN INVESTIGATION, WHOLE CLASS

14 min

MATERIALS: *Tilt Investigation Planning*, *Peer Feedback Protocol*, *Tilt Investigation Instructions*, whiteboard, dry erase markers

Share individual ideas for investigation. Call on a few students to share ideas from their peers' investigations.

Come to agreement on a class investigation plan. Display slide I. Facilitate a whole-class discussion to come to agreement on a single investigation plan. On the whiteboard, keep track of the elements students agree on. Use the following prompts as a guide:

Suggested prompts	Sample student responses	Follow-up questions
<i>How can we manipulate our independent variable to generate evidence to support or refute our directional hypothesis?</i>	We can change the amount of light we expose the plant to. We can tilt the lights to make it like the Earth.	<i>If our independent variable is about the energy from the Sun based on Earth's tilt, what can we do in our classroom to simulate that?</i>
<i>What data will we collect to provide evidence of an effect on the dependent variable?</i>	We can measure how much photosynthesis the plants do. We can see how much the BTB changes from blue to yellow.	<i>What changes do we see to matter and energy during photosynthesis?</i> <i>How can BTB help us measure that change?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>How can the class collect enough data to feel confident about the results?</i>	Each group can do the same thing and put it all together so there is a lot of data. Each group could do one kind of light on multiple tubes.	<i>What did we do in our Decomposition Investigation to generate a lot of data?</i>
<i>How will we know if our measurements are accurate?</i>	Each group can compare their results to see if they are similar. We could see what happens in another class and make sure it is similar.	<i>What did we do in our Decomposition Investigation to think about accuracy?</i>
<i>What results would support our hypothesis? Why?</i>	When the light was tilted more directly at the plants, the BTB would be bluer because carbon dioxide is being used to make sugar in the plants.	<i>BTB measures carbon dioxide in the water. How is carbon dioxide flowing during photosynthesis?</i> <i>What color change would you expect to see?</i>
<i>There are limitations to how precise the data we collect can be. What factors can you control/not control that could limit the class's ability to confidently make a claim based on evidence for the investigation.</i>	We can control temperature and make sure that all the tubes are at the same temperature.	
ADDITIONAL GUIDANCE The <i>Tilt Investigation Instructions</i> can be adapted based on student ideas you want to incorporate into the investigation. Make any edits before copying and distributing this resource to students.		

5 • NAVIGATE

3 min

MATERIALS: science notebook

Turn and Talk. Display [slide J](#). Ask students to each take one minute to share with a partner their thinking about how the evidence we collect will help us answer our question about how changes in the Earth's tilt could cause more energy and matter to be stored in plants.

End of day 1

6 • NAVIGATE

5 min

MATERIALS: science notebook

Distribute *Tilt Investigation Instructions* to each student. Display [slide K](#). Provide students with several minutes to read through the procedures and ask questions.

7 · MAP INVESTIGATION TO ZOMBIE FIRE SYSTEM

8 min

MATERIALS: science notebook

Turn and Talk. Display **slide L**. Ask students to create the mapping table on the slides in their science notebooks. Then ask students to turn and talk with a partner to consider the elements in the investigation and how they map to the zombie fire system. Call on a few pairs to share their ideas and come to a consensus as a class about how the elements map.

This part of the investigation...	is like this part of the zombie fire system ...
aquatic plant	plants in the Arctic that became peat
light bulb tilted directly at the plant	Sun when the Earth's tilt was greater
light bulb tilted indirectly at the plant	Sun when the Earth's tilt was lesser
BTB in water	air in the Arctic around the plants/peat

8 · CARRY OUT INVESTIGATIONS

17 min

MATERIALS: Earth's Tilt Investigation, *Tilt Investigation Instructions*

Share the investigation plan. Distribute *Tilt Investigation Instructions* to each student. Display **slide M**. Say, *This plan incorporates the ideas from your plans yesterday and takes into account the materials and time we have in our classroom.* Highlight ideas that individual groups contributed to the class plan.

Create data tables. Display **slide N**. Ask students to set up a data table in their science notebooks similar to the one on the slide.

 **Small groups carry out their investigations.** Display **slide O** and remind students of the safety expectations in the classroom. Organize students into small groups of 4-5 and direct groups to collect their materials and follow the class investigation plan. Students should fill their tubes and place them in the designated locations overnight. Make sure they are labeled with group names so students can easily find them in the next class. Remind students to take a photo or make a sketch of their tubes in their data tables in their science notebooks. Direct students to clean up their work stations and return any supplies to the appropriate location.

SAFETY PRECAUTIONS



Wear indirectly vented chemical splash goggles, a non-latex apron, and nitrile gloves during the setup, hands on, and takedown segment of the activity. Use caution when working with glassware, which can shatter if dropped and cut skin. Use caution when working with clamp lights - use only a GFCI protected electrical receptacle to power the lights and keep away from water sources. Also, use caution when touching the light so as to prevent burning of the skin. Immediately wipe up any spilled water off the floor to prevent slip/fall hazards. Any electrical cords must be off the floor to prevent trip/fall hazards.

9 · MAKE PREDICTIONS

5 min

MATERIALS: *Tilt Investigation Instructions*

Make predictions. Display **slide P** and ask students to record the answers to the prediction questions in their science notebooks.

10 · NAVIGATE

10 min

MATERIALS: None

Share predictions. Display **slide Q**. Call on a few students to share the predictions they made in their science notebooks. Listen for ideas related to an increase in carbon dioxide absorption (darker blue color) in tubes with more direct light and push students to articulate 1) under what conditions they think the aquatic plant will convert the most carbon dioxide into sugars and why and 2) which aquatic plant they think will have stored the most carbon and energy and why.

End of day 2

11 · NAVIGATE

2 min

MATERIALS: science notebook

Revisit predictions and data tables. Display **slide R**. Ask students to turn to their predictions in their science notebooks and review what they recorded in the previous class.

12 · DATA COLLECTION AND CLEAN-UP

16 min

MATERIALS: *Tilt Investigation Instructions*, science notebook



Conduct data collection. Display **slide S**. Students should follow the directions on *Tilt Investigation Instructions* to complete their data collection. They should record their observations in their data tables in their science notebooks.

Clean up the investigation. Display **slide T**. Instruct students to clean up their investigations, rinsing and storing their test tubes, disposing of their Elodea according to your local regulations, and recycling their foil. Make sure students wear protective eyewear during clean-up and wash their hands with soap and water after they have completed the clean-up.

SAFETY PRECAUTIONS



Wear indirectly vented chemical splash goggles, a non-latex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the activity. Use caution when working with glassware, which can shatter if dropped and cut skin. Use caution when working with clamp lights – use only a GFCI protected electrical receptacle to power the lights. Also use caution when touching the light so as to prevent burning of the skin. Immediately wipe up any spilled water off the floor to prevent slip/fall hazards.

13 · MAKE SENSE OF INVESTIGATION DATA

8 min

MATERIALS: *Tilt: Making Sense*, science notebook



Support small-group sensemaking. Display slide U. Direct student groups to *Tilt: Making Sense* and provide them with time to answer the questions. Circulate around the room and prompt them to make connections between what happened in the test tubes and what happened in the Arctic in the past.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Student identification of **evidence** generated from their investigations, such as (SEP: 3.3):

- When the energy from the lamp was direct, **more energy flowed to the plants and** more carbon dioxide from the water was **captured by the plants during photosynthesis and converted into sugar.** (DCI: LS1.C.1; CCC: 5.2)
- When energy from the lamp was less direct, **less energy flowed to the plants and** more carbon dioxide stayed in the water in the test tube/less was **captured by the plants during photosynthesis.** (DCI: LS1.C.1; CCC: 5.2)

What to do: Circulate around the room to formatively assess how students use evidence generated during the investigation. Use the following prompts:

- What happened to matter (carbon dioxide) when the light was more direct/less direct?
- What happened to the rate of photosynthesis when the light was more direct/less direct?
- What did the plant do through photosynthesis?
- Where did the carbon dioxide go in the test tubes that are bluest? What form is the carbon that was in the carbon dioxide molecules in now?
- Would the carbon have made its way into the plant without energy from the light? How do you know?
- What happened to the energy from the light? Where is it now?

Building toward 5.B.2 Plan and carry out an investigation considering type, amount, and accuracy of data to support explanations about **changes in energy flow** during **photosynthesis** under different conditions. (SEP: 3.2; DCI: LS1.C.1; CCC: 5.2)

14 · BUILDING UNDERSTANDINGS DISCUSSION

8 min

MATERIALS: *Tilt: Making Sense*, science notebook

Facilitate a Building Understandings Discussion*. Display slide V. Use the prompts below as a guide.

Suggested prompt	Sample student response
What happened in each tube?	Test tube A: Stayed more yellow. Test tube B: Turned greenish/blue. Test tube C: Turned darker blue.

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful kind of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and claims and push them to support these conclusions and claims with evidence. Students can disagree with each other, and the class does not need to reach consensus

Suggested prompt	Sample student response
<i>Why did these results occur?</i>	When the light was more direct, there was more solar energy available for photosynthesis.
<i>What happened to the light energy in the investigation? How did it drive the flow of energy and matter?</i>	Where there was more light, more matter and energy were transferred from the light and the carbon dioxide to sugar and oxygen.
<i>How does this evidence help us answer our investigation question?</i>	The light energy allowed the plant to take in carbon dioxide and turn it into sugar and oxygen.
<i>What does this evidence help us understand about the zombie fire system?</i>	The evidence from our investigation supports the information we have from the reading about how changes in Earth's tilt could have allowed for more solar energy and more energy and matter in plants. It helps us understand how there could be so much plant matter and energy in the peat in the Arctic where not a lot is growing now. In the past, there was more solar energy available in the Arctic for plants to do photosynthesis, and then when there was less energy, they died and became peat, and the permafrost formed over it.

on all ideas shared. Areas of disagreement can motivate future investigations. Helpful prompts during these kind of discussions include:

- What can we conclude?
- How did you arrive at that conclusion?
- What's your evidence?
- Does any group have evidence to support Group A's claim?
- What data do we have that challenges Group B's claim?

KEY IDEAS

Purpose of this discussion: To help students connect the evidence generated during their investigations to the matter and energy in the peat/permafrost system.

Listen for these ideas:

- When the energy from the light was more direct, more carbon dioxide was converted into sugar in the plant through photosynthesis.
- In the Earth's past, the tilt of the Earth was different, which means there was more direct solar energy.
- During this time period, more plants grew in the Arctic.
- As the Earth's tilt was reduced, less solar energy was available.
- Plants died and ice formed, trapping all the matter and energy in the peat/permafrost.

Update Personal Glossaries. Display **slide W**. At some point during the discussion, students will describe the process by which energy from the light/Sun drives the flow of energy and matter to convert carbon dioxide and water into sugar and oxygen. When this happens, pause to name and define *chemical energy*. Definitions may be similar to: energy stored because of how atoms are arranged or energy stored when atoms rearrange.

MATERIALS: Energy and Matter Storage in Plants, science notebook

Celebrate how much the class has figured out about the peat/permafrost system. Say, *You all have figured out so much about this system, going back many thousands of years to understand how the Earth was different and how those differences affect what we see now!*

Revisit energy and matter flow through photosynthesis. Display slide X. Say, *When we talked about photosynthesis before we planned our investigation, we described this equation. What did we think happens to the sugar that the plant makes during photosynthesis?* Listen for student responses such as:

- Plants use some of the sugar for energy.
- Plants store what is extra/what they do not need right away.
- Plants use the sugars to build their stems and leaves and to grow.

Suggested prompts	Sample student responses	Follow-up questions
<i>What happens to the sugar that plants make during photosynthesis?</i>	Plants use some of the sugar for energy. Plants store what is extra/what they do not need right away. Plants use the sugars to build their stems and leaves and to grow.	<i>What reaction happens when plants and other organisms use sugar for energy?</i> <i>Where does the sugar go if it is being stored?</i>
<i>How is the amount of light energy related to how much energy and matter a plant stores?</i>	The more light energy, the more sugar would be stored.	
<i>How can we collect evidence that the plant is really storing the glucose?</i>	We would need a way to see the sugar inside the plant, like how the BTB shows us the carbon dioxide in water.	

Share information about a starch test. Say, *I hear you saying that when plants have more than what they need to make sugar and survive, they would store it. Previous investigations have shown that plants can assemble sugar into large molecules for storage. Starch is one of those molecules.* Display slide Y. Remind students that they encountered long chains of glucose in Lesson 2 when they investigated peat. Let students know that you tested the Elodea for the presence of starch.

Display slide Z and talk through the starch test with students, letting them know that if sugar is present, the iodine solution will remain yellow/brown. If starch is present, it will turn a black/purple color. Ask students to predict what they think will happen. Listen for responses that indicate that if the plants were doing photosynthesis and making sugar, they might be able to store it as starch. If they were not doing photosynthesis (not in the light), they would not be able to make sugar and store it as starch.

Share results from the starch test. Display slide AA. Explain that the image on the slide shows the Elodea on the left that had been kept in the dark and the tube on the right that had been exposed to light. Ask students to share their ideas about what the evidence from the starch test tells us. Listen for students to share that the plant in direct sunlight had more starch, so it was storing more matter and energy.

ADDITIONAL GUIDANCE

One limitation of the starch test is that it only indicates the presence or absence of starch and cannot help us determine if different conditions facilitated the production of more or less starch. Prompt students to consider this limitation and what the test can and cannot help us understand.

16 · CONSTRUCT AN EXPLANATION

8 min

MATERIALS: science notebook



Link evidence to claims. Display slide BB. Say, *Let's see if we can connect what we figured out about starch back to the peat in the zombie fire system.* Using the evidence collected in the starch test, ask students to work with their partners to identify evidence to support the claim: Increased energy from the Sun caused matter and energy to be stored as carbohydrates in the peat in the zombie fire system.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Evidence to support the claim (SEP: 6.4), such as:

- In **direct light**, more **carbon dioxide** from the water **flowed into** the plants through photosynthesis. (DCI: LS1.C.2; CCC: 5.4)
- Plants in **direct light converted sugars to starch** and plants in the dark did not. (DCI: LS1.C.2)
- The **energy from the Sun drives the flow of matter from the atmosphere to the plant.** (DCI: LS1.C.2; CCC: 5.4)

What to do: Consider walking around with a clipboard and your roster to make sure each student has cited evidence to support the claim. Ask questions such as:

- What could cause there to be changes in the matter and energy that would result in peat containing many large carbon-based molecules?
- Where does the energy come from to make sugar and starch?
- Where is the matter moving to/from?
- How does what we saw in our investigation today help us understand what happened in the past?
- How can we be confident that the plants we have today perform photosynthesis in the same way plants did in Earth's past?
- What might have happened to plants in the Arctic when solar energy decreased as Earth's tilt changed?

If students struggle with oral explanation, invite them to use pictures and/or words to represent their evidence.

Building toward 5.C. Apply scientific reasoning to link evidence to claims about how **energy from the Sun drives the flow of matter from carbon dioxide in the atmosphere to sugar molecules assembled into larger molecules found in peat.** (SEP: 6.4; DCI: LS1.C.2; CCC: 5.4)

ADDITIONAL GUIDANCE

Please note that while in this lesson we are only testing for starch, peat most likely contains other carbon-based molecules in addition to starch. Lignin and cellulose are the major molecules in peat (Rana and Viraraghavan, 1987; Viraraghavan and Rana, 1991).

17 · NAVIGATE: UPDATE PROGRESS TRACKERS

3 min

MATERIALS: *Fires Progress Tracker*

Update Progress Trackers. If time permits, display **slide BB** and ask students to complete a new row in *Fires Progress Tracker*. One possible representation of a completed Progress Tracker is shown below.

	What we figured out (WWFO)	How does WWFO help us make progress on our Driving Question about zombie fires?	How does WWFO connect to me or my community, or have a larger-scale impact?	What questions do I have now?
Lesson 5: How do zombie fires disrupt the flow of energy and cycle of matter in Arctic ecosystems?	-Through photosynthesis, plants convert carbon dioxide and water into sugar and oxygen. -More solar energy means more carbon dioxide is captured and stored by plants as sugar and releases oxygen. -Plants convert excess sugar into larger carbon-based molecules.	We noticed the peat in zombie fires burned for a long time. Figuring out that the plants that made the peat contain so many carbon molecules and so much energy because those plants grew when there	We wonder what this means for plants in our community or with changes in our area over time.	How does this affect plants in other systems? How will this change in the future?

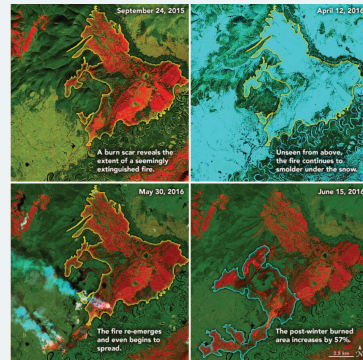
LESSON 6: How do zombie fires disrupt the flow of energy and cycle of matter in Arctic ecosystems?

PREVIOUS LESSON *We investigated how so much plant matter got to be stored as peat under the permafrost. We read about the formation of peat thousands of years ago and the conditions on Earth at that time. We planned and carried out an investigation to generate evidence to support our claims about the transfer of energy from the Sun to carbon-based molecules in plants. We constructed an oral explanation for how peat can contain large molecules.*

THIS LESSON

PUTTING PIECES TOGETHER

2 days



NASA Earth Observatory, Joshua Stevens

We develop our class consensus model to put together all of the evidence we collected throughout the first half of the unit to construct an explanation for zombie fires. Then we return to our Driving Question Board to update our questions and ideas for investigation to make progress on our Unit Question: What causes fires in ecosystems to burn and how should we manage them?

NEXT LESSON *We will use case studies to investigate places, lands, and waters where global carbon sinks are burning with more frequency. We will analyze how energy and matter are moving through each system and discuss the historical events and decisions that contributed to the current conditions that make carbon sinks more likely to burn.*

BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3, HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ESS3-6, HS-ETS1-2



WHAT STUDENTS WILL DO

6.A Develop, revise, and use a model based on evidence to explain how inputs of matter and energy flow through different scales of the zombie fire system as the components are recombined to form different outputs. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)

6.B Construct an explanation based on evidence about how photosynthesis and cellular respiration change energy and matter in the biosphere, geosphere, and atmosphere and predict what might happen in the future. (SEP: 6.2; DCI: LS.2.B.3; CCC: 5.2)

WHAT STUDENTS WILL FIGURE OUT

- Photosynthesis captures energy from sunlight and is converted to chemical energy in carbon-based glucose fuel, taking carbon out of the air and into the plants/peat. Plants that have extra energy and matter, assemble glucose created into larger molecules.
- Plants in the Arctic die and get submerged where it is too cold for decomposition to happen quickly. Energy in the plants is kept underwater when generations of plants die on top of one another. More and more matter and energy remain in the peat.
- Peat is made of partially decomposed layers of plants.
- When permafrost thaws, peat is exposed. Peat can now decompose and burn.
- Zombie fires burn huge carbon sinks in the peat/permafrost system and release tons of carbon into the air.
- In the recent past, peat was frozen in permafrost, keeping matter and energy, but if in the future more permafrost thaws, then more matter and energy will be available.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Summarize what we have figured out so far and motivate pausing to make sense of it all.	A	
2	5 min		TAKE STOCK OF COMMUNITY AGREEMENTS Arrange students in a Scientists Circle to reflect on Community Agreements.	B-C	3 x 3 sticky notes (green), 3 x 3 sticky notes (yellow), Community Agreements
3	15 min		BRAINSTORM COMPONENTS FOR GOTTA-HAVE-IT CHECKLIST Guide students in brainstorming a list of components, interactions, and mechanisms needed in consensus models.	D-F	whiteboard, dry erase markers
4	15 min		DEVELOP CLASS CONSENSUS MODEL Develop a class consensus model to explain what causes zombie fires and what the consequences are.	G-K	chart paper and chart paper markers, 3x3 sticky notes, <i>Discussion-Mapping Tool</i>
5	5 min		NAVIGATE AND REFLECT ON DISCUSSION MAP Facilitate a discussion about patterns in the discussion map and celebrate progress.	L	discussion map
End of day 1					
6	10 min		NAVIGATE: SELF-REFLECTION Prepare for assessment and reflect..	M	<i>Fires Progress Tracker</i>
7	20 min		CONSTRUCT A SCIENTIFIC EXPLANATION FOR ZOMBIE FIRES Support students in constructing an explanation for zombie fires.	N	completed <i>Fires Progress Tracker</i> , <i>Zombie Fire Explanation</i> , <i>Zombie Fire Explanation Feedback Guidance</i>
8	10 min		REVISIT THE DRIVING QUESTION BOARD Identify questions answered/partially answered and questions remaining unanswered, and add a new part to the unit question.	O-P	Driving Question Board, Related Phenomena poster, 3x3 sticky notes, chart paper markers
9	5 min		NAVIGATE Motivate where we are going in the next lesson set.	Q	Ideas for Investigations chart paper from Lesson 1
End of day 2					

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials	- science notebook 3 x 3 sticky notes (green) 3 x 3 sticky notes (yellow) <i>Fires Progress Tracker</i> - completed <i>Fires Progress Tracker</i> <i>Zombie Fire Explanation</i> - science notebook. <i>DQB Questions</i>		- Community Agreements - whiteboard - dry erase markers - chart paper and chart paper markers 3x3 sticky notes <i>Discussion-Mapping Tool</i> - discussion map <i>Zombie Fire Explanation Feedback Guidance</i> - Driving Question Board - Related Phenomena poster - chart paper markers - Ideas for Investigations chart paper from Lesson 1

Materials preparation (5 minutes)

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

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

Be sure your Community Agreements are visible for reference during this lesson.

Day 1:

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

Day 2:

- Make sure chart paper and chart paper markers, or an alternative way to record the consensus model, are available.
- Make sure the Driving Question Board, Related Phenomena, and Ideas for Investigations posters (from Lesson 1) are accessible.
- Add questions from the class DQB into *DQB Questions* before copying for students.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

During this culminating lesson of Lesson Set 1, students put the pieces together to model and explain changes in matter and energy within the zombie fire system. Students use the evidence collected in Lesson Set 1 to support their explanations. The DCI elements that students put together in this lesson include:

- HS-LS1.C.3: As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7)
- HS-LS2.B.3: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, ~~oceans~~, and geosphere through chemical, physical, geological, and biological processes. (HS-LS2-5)

Students continue to use and develop elements from the focal practices of the unit *developing and using models* and *constructing explanations*. Students are supported in learning to use the focal practices through tools such as the Gotta-Have-It Checklist to help them develop a class consensus model and individual explanation for zombie fires.

Students use and develop elements from focal crosscutting concepts *systems and system models*, and *energy and matter* throughout the lesson and focus on the flow of energy and matter in the zombie fire system.

In this lesson, students will revise a co-constructed definition for *zombie fires*, which they should add to their Personal Glossaries. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

While carbon cycling or feedback loops/effects/mechanisms will not formally be defined in this lesson, students will develop these ideas in Lesson 7 when they begin to make sense of how increasing fires contribute to the global carbon cycle.

Students have not explored the negative consequences of rising carbon dioxide. Additionally, students have not applied their systems model to a global scale or other ecosystems. They will build those ideas out across Lessons 7 through 11. It can be disheartening to see the effects of increased carbon dioxide and temperature on systems. Students will develop action plans at the end of Lesson Set 3 to remedy some of the effects of increased carbon in the atmosphere.

At this point in the unit, students have yet to relate ideas about photosynthesis and cellular respiration to transfer of energy and matter through food webs. These ideas will be motivated and addressed in Lessons 10 and 11 as students begin to think more deeply about fire management.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

5 min

MATERIALS: science notebook

Facilitate a discussion about what we have figured out so far. Display slide A. Say, *We have figured out a lot of big science ideas over the past few lessons. What are some of the ways that we make sense of a lot of ideas? How do we make connections between ideas that we have?* Pause to give students an opportunity to share their ideas about what practices they might engage in.

Listen for ideas such as:

- We use pictures and/or words to explain concepts.
- We develop models to show relationships between components and ideas.
- We communicate our ideas with others.
- We construct explanations.

Say, *Today, we are going to take what we have figured out and develop a class consensus model we can use like scientists to explain: What causes zombie fires to burn under the ice and what are the consequences?*

2 · TAKE STOCK OF COMMUNITY AGREEMENTS

5 min

MATERIALS: 3 x 3 sticky notes (green), 3 x 3 sticky notes (yellow), Community Agreements

Take stock of our Community Agreements. Say, *This is a good place to stop and remind ourselves of all of our Community Agreements.* Display slide B. Display or point to the Community Agreements. Have students add 3 x 3 sticky notes to mark one agreement that they think we are doing well and one agreement that they think we need to improve on. * Use the prompts below to support students with this task and accept all student responses.

- What patterns do you see in the 3 x 3 sticky notes?
- Which agreements are we doing well with?
- Which agreements could we improve on?
- What are some ways we might improve at _____ (specific agreement)?

Identify today's focal agreements. Say, *Today we are going to continue to build consensus around what is happening in the zombie fire system. Take a moment to consider how to focus on and balance two key Community Agreements at the same time.* Display slide C. Say, *We want to move our thinking forward while also being respectful. Turn and talk with a partner about how we can support both of those agreements.* Call on a few students to share their ideas with the whole class. *

* ATTENDING TO EQUITY

Universal Design for Learning: Using different representations such as a smiley and heart instead of just colors allows for increased access to the task, especially for students with vision differences.

* ATTENDING TO EQUITY

Building classroom culture and Community Agreements: As students share ideas to reach a consensus and revised model, it is important that they think about how to be respectful while moving the class's thinking forward. This is a good place to emphasize that respect does not mean always agreeing, and challenging each other's ideas needs to happen respectfully. This can look like disagreeing with ideas, not people, being willing to listen carefully to our classmates, and changing our thinking about a problem.

When choosing respect as a focal agreement, it is important to remember that how we define respect can be culturally

constructed, which is why we ask students to explicitly name what respect looks like/sounds like during the development of agreements in Lesson 1. Be aware of how the term respect can be used to reproduce gendered or racialized ideas (i.e., bossy vs. leader; angry vs. passionate) and steer students back to the more detailed Lesson 1 agreements when necessary.

3 · BRAINSTORM COMPONENTS FOR GOTTA-HAVE-IT CHECKLIST

15 min

MATERIALS: science notebook, whiteboard, dry erase markers

Develop a Gotta-Have-It Checklist. Display **slide D**. Say, *If we are going to make a detailed model to explain: What causes zombie fires to burn under the ice and what are the consequences?, we need to revisit what we have figured out so far in the unit. What are all the components we need to explain what happens with the matter and energy in the zombie fire system?* Ask students to share as a class all of the possible components needed to explain what is happening with the matter and energy in the zombie fire system. Make sure this list is visible to students while they complete their Gotta-Have-It Checklists.

Have students title a new page *Gotta-Have-It Checklist* in their science notebooks. Display **slide E**. Say, *In your notebook, you will need a table with three columns labeled: Components, Interactions, and Mechanisms.*

ADDITIONAL GUIDANCE

Students should already have familiarity with components, interactions, and mechanisms from prior NGSS grade bands and *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. If not, this is a good time to revisit definitions and revise or add new entries to students' Personal Glossaries. Sample definitions may be similar to: Component: of the system; Interaction: how the components affect each other; Mechanism: what explains the interactions (both seen and unseen).

Turn and Talk. Display **slide F**. Say, *Working with your partner, you will go through your science notebook, Progress Tracker, and handouts to complete the first row of the Gotta-Have-It Checklist. We will complete the rest of this checklist later. Pick two components from our list and write them in the first column. Then in the second column, explain how they interact. In the third column, describe a possible mechanism that explains their interaction.* Consider assigning two components for each pair of students to define interaction and mechanism or letting pairs choose their components to get an array of ideas. Encourage students to use all of their handouts, Progress Trackers, and any other materials in their science notebooks. After students have had a few minutes to complete the first row, pause and call on a few pairs to share their ideas and write an example on a whiteboard or chart paper. *

* ATTENDING TO EQUITY

Supporting emergent multilinguals:

Students who are learning English benefit from redundancy of content and vocabulary. One way to give students the opportunity to hear ideas again is to revoice them. For example, after students have shared an idea, check to clarify what students agree upon by asking, "So I'm hearing _____ and _____. Do I have that right?" For all science students, but particularly those who are learning English, the opportunity to hear scientific language in varied contexts is fundamental to the development of disciplinary literacy.

Listen for students to summarize one or more of the following:

How do zombie fires burn under ice,, releasing so much carbon dioxide?		
Components	Interactions	Mechanisms
Peat and permafrost	Peat is buried/frozen in the permafrost.	The permafrost keeps the matter in peat cold and trapped away from oxygen, so it does not decompose.
Permafrost and atmosphere	The permafrost is decreasing/melting due to how it interacts with the warmer atmosphere.	Since the air temperature is warmer, the permafrost was once all frozen and now is thawing.
Peat and decomposers	The matter in peat decreases when it interacts with the decomposers that consume it.	Decomposition happens through cellular respiration, where carbon-based molecules (such as sugar/glucose) in the peat plus oxygen are converted/rearranged to carbon dioxide, water, and energy.
Decomposers and atmosphere	Decomposers increase their activity when they interact with warmer temperatures and oxygen in the atmosphere.	Decomposition/cellular respiration slows down when it is colder or there is less oxygen and is faster when it is warmer or there is more oxygen. This adds more carbon dioxide to the atmosphere when it is warmer.
Plants and atmosphere	Plants interact with the Sun, carbon dioxide, water, sugar, and oxygen in the atmosphere.	Carbon dioxide and water are captured using energy from the Sun and the mechanism of photosynthesis. The plants store carbon and chemical energy in the sugar (glucose) and release oxygen.
Plants and the Sun	Plants interact with changes in solar radiation from the Sun.	Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds (sugars/glucose), using the mechanism of photosynthesis to grow and live. Since there were so many plants capturing energy from increased solar radiation, when all of those plants died, they piled up in the wetlands without decomposition. When the solar radiation decreased, the mechanism of freezing created permafrost. This trapped the matter and chemical energy in the peat (that was once plants), stopping the mechanism of decomposition. If the Arctic has the right tilt, there is a lot more solar radiation available there to warm the atmosphere, and plants convert more solar energy to chemical energy.

Fire and peat/other plants	Fire interacts with the peat and other plants through burning.	Fire burning releases matter (carbon dioxide and water) and energy (heat and light) stored in peat and other plants (as chemical energy).
----------------------------	--	---

 **Complete the Gotta-Have-It Checklist.** Have students draw a line to create a new row after each set of components. Encourage students to continue to fill in the rows of their checklists and add a line after each one. Please note that student lists will include many of the components, interactions, and mechanisms listed above but likely not all. Remind students that the purpose of this checklist is to make sure that as a class we have everything we figured out through our investigations accounted for when we make a consensus model for explaining what causes zombie forest to burn under the ice and what the consequences are.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: See the sample Gotta-Have-It Checklist above for specific look-fors.

What to do: Guide students to return to the sensemaking they have done throughout Lessons 1-5. As you circulate around the room, prompt students to use *evidence* (SEP 6) and *energy and matter* (SEP 5) to explain their thinking.

- What level/scale of the system are you using here?
- What changes do you see to energy and matter?
- Look back through your notebook and Progress Tracker. What evidence do you have to support changes in your thinking since Lesson 1?

If you identify gaps in a student's understanding, encourage a peer to build on the ideas they have shared to explain what is happening to the matter and energy in the zombie fire system. Focus on a single lesson and return to the components, interactions, and mechanisms, asking them to help identify ways to use pictures and/or words to make the invisible mechanisms visible.

Building toward 6.A Develop, revise, and use a model based on evidence to explain how inputs of matter and energy flow through different scales of the zombie fire system as the components are recombined to form different outputs. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)

4 · DEVELOP CLASS CONSENSUS MODEL

15 min

MATERIALS: science notebook, chart paper and chart paper markers, 3x3 sticky notes, *Discussion-Mapping Tool*

Introduce the discussion-mapping tool. Display *slide G*. Let students know that you have a tool that can support the class in making progress on the Community Agreements *Respectful* and *Moving our science thinking forward*. Say, *We are going to use a tool today to map our discussion. This will help us think about how we can all work together and respect each others' contributions when we are discussing new ideas to move our thinking forward.*

Establish student volunteers. Choose two student volunteers to help the class map the discussion. One student can map the first half of the discussion and then pass the map on to the other student, or they can work together for the entire discussion. Consider reaching out ahead of time to students who you think may want to fulfill these roles. Give a copy of *Discussion-Mapping Tool* to the students who have volunteered to facilitate.

* ATTENDING TO EQUITY

Universal Design for Learning: Use *representations* like color coding and/or letter or number coding to foreground parts of the model. Create a key to track what colors, symbols, or letter or number codes represent different parts of the system. While color coding is a useful way to quickly reference the parts of the model, letter or number coding helps ensure accessibility for any student who may be color-blind. If color coding is used, consider a color palette that uses orange, blue, black, or dark brown.

ADDITIONAL GUIDANCE

Discussion-Mapping Tool gives students a visual representation of the discussion patterns in the class. Use lines to track how the discussion moves between speakers, including yourself. After you track the first several moves, pause the discussion to show students what the map looks like. Ask for a student volunteer to map the rest of the discussion. This can be a way to involve a student who is less comfortable speaking publicly. While *Discussion-Mapping Tool* includes codes to mark different types of contributions, you may want to track just discussion patterns the first few times you use the tool. As students become more comfortable with discussion-mapping, you can add in contribution codes.

Develop a class consensus model. * * Display **slide H**. Ask students to gather in a Scientists Circle. Have students bring their science notebooks and their completed Gotta-Have-It Checklists. Say, *What components from our Gotta-Have-It Checklists do we need in our model to explain: What causes zombie fires to burn under the ice and what are the consequences?* As students share their ideas, write the components on sticky notes and add them to the poster. Then follow the same routine with interactions and mechanisms for each pair of components. Display **slide I** for additional prompts.

As students suggest components, interactions, and mechanisms, record which students offer ideas on *Discussion-Mapping Tool*. Take a moment to show the tool to students and then set up your student volunteer(s) to continue to map the discussion before moving to the next set of components. You may want to use a clipboard to make it easier to pass around.

As students share their ideas and you record them in the class consensus model, ask students to clarify what evidence supports the idea. Recall the conventions used earlier in the unit: a wavy line for energy and a straight, dashed line for matter.

KEY IDEAS

Purpose of this discussion:

- To help students connect what components are essential for explaining how zombie fires burn and release so much carbon, how those components interact, and what the underlying mechanisms are in the system.
- Prepare students to construct an individual explanation using evidence.

Look/listen for these ideas: See the *Gotta-Have-It Checklist* for what students will include in their models.

Continue adding components, interactions, and mechanisms. Display **slide J**. Encourage students to add and build on each other's ideas until the class is confident in their model. *

Review the model with students. Display **slide K**. Say, *Now that we have developed this model, does it explain what causes zombie fires to burn under the ice and the consequences? What is missing that we need? Do we have any more evidence that could support our ideas?* If there are missing components, make sure to add them to the model. * See one possible representation of this model on the following page.

ADDITIONAL GUIDANCE

Now is a good time for students to revisit their Personal Glossaries and the definition they co-constructed for zombie fires earlier in the unit. They may also want to revisit other definitions and revise them based on what they have figured out throughout Lesson Set 1.

* STRATEGIES FOR THIS CONSENSUS DISCUSSION

A Consensus Discussion is different from other kinds of discussions because the purpose of the discussion is to converge on one or more ideas that the whole class agrees upon. In this discussion, your classroom community is pressing toward a common (class-level) explanation of how zombie fires can burn under ice and release so much carbon.

During this work, the class resolves disagreements where possible. Your role is to help students see where they agree and where they still disagree. Helpful prompts include:

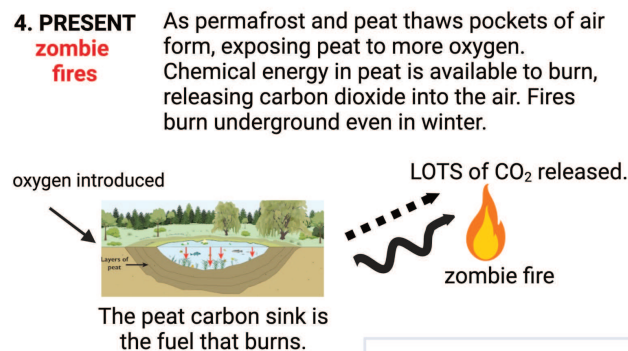
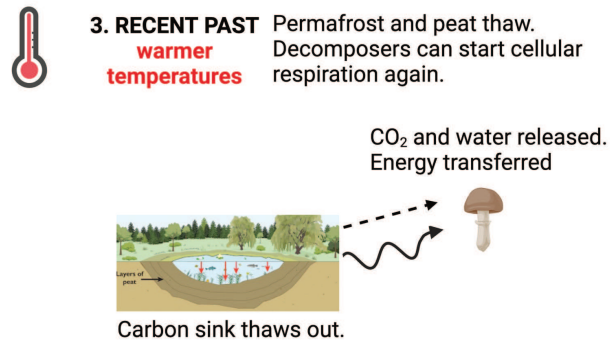
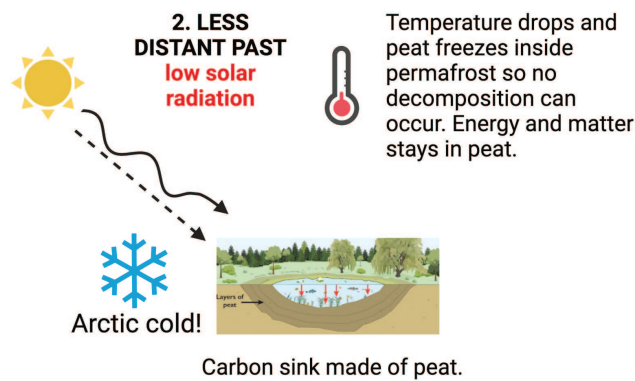
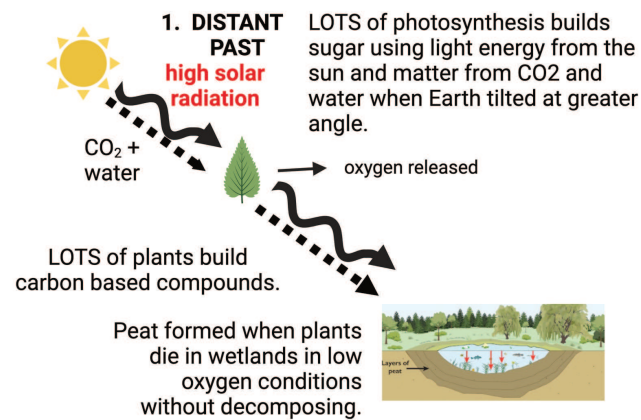
- What ideas are we in agreement about?
- Would anyone have represented this idea in a different way?
- Who feels like their idea is not quite represented here?
- Are there still places where we disagree? Can we clarify these?
- What evidence do we have to support _____?

* SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

Over the course of the unit, students will begin thinking about system models as an important aspect of scientific work in their classrooms. It is important to make students aware of the crosscutting concepts they develop and use them in the same manner and to the same degree that students develop and use disciplinary core ideas and science and engineering practices. In this instance, articulating the important parts of the system and how the parts interact will help students make sense of complex phenomena.

* ATTENDING TO EQUITY

What causes zombie fires to burn under the ice and what are the consequences?



CO₂=carbon dioxide
 ~~~~~ Energy flow  
 - - - - - Matter flow

Illustrations created by OpenSciEd in BioRender

Asking students to restate what another student has said supports the goal of students listening carefully to each other so that they can work with others' ideas. This move can feel odd to students at first, so it will help if you let them know ahead of time that you will be asking this.

## 5 · NAVIGATE AND REFLECT ON DISCUSSION MAP

5 min

**MATERIALS:** science notebook, discussion map

**Reflect on the discussion map.** Display **slide L**. Display the discussion map by inserting an image into **slide L** or by projecting it in another way. Have students observe the map and write down any patterns they notice into their science notebooks. Give students a few minutes to complete this task individually. Say, *After looking at this map, what are some things we should consider during our discussions to make sure that everybody plays a role in moving our thinking forward?* \* Listen for responses such as:

- We should ask questions and respond to each other instead of directing our responses to the teacher.
- We should invite people into the discussion who have not had a chance to add to the discussion.
- We should monitor our airtime and give other people time to talk.

**Celebrate progress and share next steps.** Highlight for students how much they have figured out about the causes and consequences of zombie fires. \* Let students know that in the next class, they will engage in an embedded assessment where they will use the class consensus model to construct an explanation. If you have not handed back *Peat/Permafrost Explanation*, with feedback, do so at this time. Students should review their *Peat/Permafrost Explanation* and Progress Trackers and use them on the assessment. Ask students what questions they have at this time.

### \* ATTENDING TO EQUITY

**Building classroom culture and norms:** The goal of this reflection is to notice whole-class patterns and decide how all students can move discussions forward as a community. Avoid addressing the contributions or behaviors of specific students. If they are brought up, prompt students to return to the class-level patterns they observed, saying, *Let's look at the whole map. What suggestions can we make that would support our whole class community?* This is also an opportunity to remind students that *Discussion-Mapping Tool* captures only spoken contributions and to acknowledge that non-verbal participation and listening closely are also valued contributions.

### \* ATTENDING TO EQUITY

**Building classroom culture and Community Agreements:** It is important to celebrate class progress along the way to explaining our anchoring phenomenon. Figuring ideas out through inquiry and discussion may be new or challenging for some students, and taking a moment to celebrate steps along the way can help them recognize the progress they are making.

End of day 1

## 6 · NAVIGATE: SELF-REFLECTION

10 min

**MATERIALS:** *Fires Progress Tracker*, science notebook

**Prepare for an assessment.** Instruct students to find *Fires Progress Tracker*, *Peat/Permafrost Explanation* and their Gotta-Have-It Checklists in their science notebooks.

**Use crosscutting concepts and science and engineering practices to review progress.** Ask students to turn and talk about the prompts to self-assess their progress with a partner on **slide M**:

- How have you used the crosscutting concept of energy and matter in our investigations to figure out the zombie fire system?
- How did you use evidence to support your explanations throughout Lesson Set 1?

## 7 · CONSTRUCT A SCIENTIFIC EXPLANATION FOR ZOMBIE FIRES

20 min

**MATERIALS:** science notebook, completed *Fires Progress Tracker*, *Zombie Fire Explanation*, *Zombie Fire Explanation Feedback Guidance*

**Orient students to the Zombie Fire Explanation.** Display slide N. Distribute *Zombie Fire Explanation* and give students a few minutes to read over the task and ask clarifying questions. Encourage students to use their Progress Trackers, Gotta-Have-It Checklists, and science notebooks as resources as they complete the task. Let students know you have added an SEL check-in on the last page of their explanation. You can tear this off separately and have them share it with a trusted adult. When they have completed the task, collect *Zombie Fire Explanation* from each student. \* \*

### ASSESSMENT OPPORTUNITY

**What to look/listen for in the moment:** See *Zombie Fire Explanation Feedback Guidance* for guidance.

**What to do:** Collect *Zombie Fire Explanation* from each student. Provide feedback using *Zombie Fire Explanation Feedback Guidance* and return to students. If students struggle to construct an explanation based on evidence, provide opportunities for them to try again after investigating other carbon sinks and the carbon cycle in Lessons 7 and 8. These additional sources of evidence and application to other carbon sinks can help students to revise their thinking about zombie fires.

**Building toward 6.B** Construct an explanation based on evidence about how photosynthesis and cellular respiration change energy and matter in the biosphere, geosphere, and atmosphere and predict what might happen in the future. (SEP: 6.2; DCI: LS.2.B.3; CCC: 5.2)

### \* ATTENDING TO EQUITY

**Social and Emotional Learning:** This lesson focuses on the science that explains energy and matter in the zombie fires system. It includes social and emotional learning and social justice connections to students' experiences or local communities. In Lesson Sets 2 and 3, students will make additional connections with scientists with multiple identifiers, and with marginalized groups, information about how systems of oppression are maintained or disrupted, and opportunities for students to see themselves as agents of change through individual or collective action. At this time, it is likely that students will begin to think about their role and ability as change makers. Respect this shift in thinking and encourage the class to continue their mission to find out more so they can be better agents of change.

### \* SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Depending on students' experience with writing evidence-based explanations, you may want to provide additional scaffolds for each prompt. The scaffolds should ask them to first identify the sources of evidence they can cite from their investigations. Second, they should ask students to identify the important science ideas from their Progress Trackers that they think are relevant. If students need further support, use the sentence starters such as those found on *Peat/Permafrost Explanation*.



## 8 · REVISIT THE DRIVING QUESTION BOARD

10 min

**MATERIALS:** science notebook, *DQB Questions*, Driving Question Board, Related Phenomena poster, 3x3 sticky notes, chart paper markers

**Revisit the class consensus model.** Display **slide O**. Say, *We have figured out quite a lot about: What causes zombie fires to burn under the ice and what are the consequences? Let's check in on our progress and see if we can use our model and explanation for more than just zombie fires?* Guide students in a whole-class discussion using the prompts below as a guide. \*

| Suggested prompt                                                                                                                           | Sample student response                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>How have our feelings changed or intensified since we began figuring out about fires/zombie fires?</i>                                  | Accept all responses.                                                                                                                                                                                                                                                                            |
| <i>What progress do we still need to make on our unit question: What causes fires to burn in ecosystems and how should we manage them?</i> | We need to see what happens to the smoke/carbon dioxide after it leaves the system where the fire started.<br><br>We should see if there is something we can do about decreasing zombie fires or other fires.<br><br>We predict this will become worse in the future, but we need more evidence. |
| <i>What new questions do we have?</i>                                                                                                      | We need to see if there are other places where this is happening.                                                                                                                                                                                                                                |
| <i>How can we evaluate our progress thus far?</i>                                                                                          | We could go back to the DQB and see which questions we have answered!<br><br>We could see which of our investigations we have already completed.                                                                                                                                                 |

**Revisit the Driving Questions.** Distribute *DQB Questions* with the list of questions developed on the Driving Question Board. Have students work individually to mark questions they think the class has answered using the key on the handout and **slide P**.

- We did not answer this question or any parts of it yet: **O**.
- Our class answered some parts of this question, or I think I could answer some parts of this question: **✓**.
- Our class answered this question, or using the ideas we developed, I could now answer this question: **✓+**.

Say, *What are the questions that we have left to answer? Can any of those questions help us make progress on filling in what our model does not yet explain? Can we explain any of our related phenomena?* \* Give students a moment to identify key questions and share. In addition, offer students the opportunity to add new questions to the Driving Question Board. Listen for students to add questions such as:

- Are there other carbon sinks that are burning?
- Are there other ecosystems having similar issues?
- Where are other fires happening?
- Why is it bad when zombie fires release so much carbon dioxide?
- How can we stop/manage wildfires?
- Are other places increasing in temperature and seeing more/worse fires?
- Are there any other human or nonhuman populations affected by fire?
- What are the effects on larger-scale systems from fires?
- What happens if more peat or other carbon sinks make more matter and energy available?

### \* ATTENDING TO EQUITY

Use talk strategies to draw out a wide variety of ideas from a larger pool of students.

- If it feels like students do not have any more ideas, count to ten in your head to give students more time to consider.
- Have students jot down some ideas in their notebooks after their partner talks and before sharing. This can be particularly supportive for emergent multilingual students.
- Use questions to push students' thinking to new contexts and provide more opportunities for students to make connections to their experiences.

### \* ATTENDING TO EQUITY

**Universal Design for Learning:** Use this opportunity to revisit or identify new examples of phenomena from students' own contexts. Highlight examples that involve fires happening in other places or in other circumstances, similar to what we think is happening with the zombie fires. This move can increase student *engagement* by broadening the class mission to explain not only the zombie fire phenomena but also local and relevant phenomena.

After hearing the new questions students add, say, *It sounds like we are wondering about a lot more than just zombie fires* (reference the Related Phenomena poster) *and if there is something we can do to stop or reduce fires. Can someone suggest a new Driving Question that includes these ideas?* Listen for students to suggest questions like:

- What causes fires in other ecosystems to burn?
- Why are carbon sinks burning?
- What are the effects of carbon sinks burning?
- How are other populations and places/lands/waters (human and nonhuman) affected by fire?

Now is a good opportunity to organize the remaining questions into two sections to align with the upcoming lesson sets. The Lesson Set 2 questions is, *How is global carbon cycling affected by fire?* and the Lesson Set 3 question is *How do we design solutions to manage the impacts of fires?* Ask students to consider themes they see in the unanswered questions and have them suggest ways to organize them.

## 9 • NAVIGATE

5 min

**MATERIALS:** science notebook, Ideas for Investigations chart paper from Lesson 1

**Generate ideas for new investigations.** Display **slide Q**. Say, *We have some really great questions on our DQB. How could we start to investigate these unanswered questions? What data do we need? Choose one question or category of questions from our Driving Question Board and turn and talk with a partner to consider how we might investigate in our classroom? After you have discussed one question/set of questions, move on to another.*

Accept all ideas and add them to the Ideas for Investigations chart paper. Student ideas may include the following:

- We should see if there are other places with carbon sinks (that are burning).
- We need to research if there are other places that are getting warmer.
- We should see what happens when lots of carbon dioxide is added to the air.

Ask, *Where do you think we should start next time?* Listen for students to share that we need to know if and where carbon sinks are in other ecosystems that might be burning.

Thank students for sharing their ideas and tell them that the class will start the next lesson by thinking about those other ecosystems with carbon sinks.

## Additional Lesson 6 Teacher Guidance

### SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

**CCSS.ELA-LITERACY.W.9-10.4** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Students produce a final explanation of what is happening in zombie fires burning under the ice to release so much carbon at the end of this lesson set.





# LESSON 7: What is happening to carbon sinks in other ecosystems?

**PREVIOUS LESSON** We developed our class consensus model to put together all of the evidence we collected throughout the first half of the unit to construct an explanation for zombie fires. Then we returned to our Driving Question Board to update our questions and ideas for investigation to make progress on our Unit Question: What causes fires in ecosystems to burn and how should we manage them?

## THIS LESSON

### INVESTIGATION

2 days



We use case studies to investigate places, lands, and waters where global carbon sinks are burning with more frequency. We analyze how energy and matter are moving through each system and discuss the historical events and decisions that contributed to the current conditions that make each carbon sink more likely to burn. We develop small-group models to help us come to consensus on the conditions that make carbon sinks more likely to burn. We wonder what the consequences and large-scale impacts are of fires from all of these ecosystems. We also wonder about ways to manage fires into the future.

**NEXT LESSON** We will investigate the effect of increased carbon dioxide on temperature with a bottle system designed to simulate fires in ecosystems. We will develop directional hypotheses and collect evidence to support our hypotheses. We will revise our hypotheses to explain the relationship between atmospheric carbon dioxide and temperature at the global scale and investigate data collected by scientists.

## BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3, HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



## WHAT STUDENTS WILL DO

**7.A** Critically read scientific literature adapted for classroom use to obtain information and summarize complex ideas about how changes to carbon sinks in ecosystems affect how matter and energy are exchanged between components of the system. (SEP: 8.1; DCI: LS2.B.3; CCC: 5.2)

**7.B** Develop, revise, and use a model to explain how energy and matter flow between the biosphere and atmosphere through biological processes and fire. (SEP: 2.3; DCI: LS2.B.3; CCC: 5.2)

## WHAT STUDENTS WILL FIGURE OUT

- Many different ecosystems have carbon sinks created from the flow of energy and matter into plants by photosynthesis.
- There are common climate-related and human-caused factors in ecosystems that make the energy and matter in carbon sinks more likely to burn.
- Fire increases the flow of matter and energy from the biosphere to the atmosphere.

## Lesson 7 • Learning Plan Snapshot

| Part         | Duration |                                                                                     | Summary                                                                                                                                                                       | Slide | Materials                                                                                                                                                                                                                                                                      |
|--------------|----------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1            | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Support students in generating and prioritizing questions and next steps.                                                                                  | A-D   | Ideas for Investigations and Related Phenomena posters from Lessons 1 and 6                                                                                                                                                                                                    |
| 2            | 7 min    |                                                                                     | <b>EXPLORING GLOBAL WILDFIRES</b><br>Interpret maps to determine if and where other carbon sinks are burning.                                                                 | E-G   |                                                                                                                                                                                                                                                                                |
| 3            | 15 min   |    | <b>INVESTIGATE CASE STUDIES OF CARBON SINK FIRES</b><br>Investigate case studies of fires in other carbon sinks.                                                              | H-L   | <i>Making Sense of Case Studies, Tonlé Sap Carbon Sink (Cambodia), California's Carbon Sink, Cerrado Carbon Sink (Brazil), Victoria Carbon Sink (Australia), Great Dismal Swamp</i> , access to internet-connected device for students reading <i>California's Carbon Sink</i> |
| 4            | 13 min   |                                                                                     | <b>DEVELOP SMALL-GROUP MODELS OF CARBON SINK ECOSYSTEMS</b><br>Develop small-group models of each fire system/carbon sink.                                                    | M     | chart paper, chart paper markers, <i>Sample Models</i>                                                                                                                                                                                                                         |
| 5            | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Facilitate a Social and Emotional Learning check-in.                                                                                                       | N     |                                                                                                                                                                                                                                                                                |
| End of day 1 |          |                                                                                     |                                                                                                                                                                               |       |                                                                                                                                                                                                                                                                                |
| 6            | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Ask students to review feedback individually then review their ideas for model revision with their group.                                                  | O     | <i>Making Sense of Case Studies</i> , Group models from case studies, <i>Tonlé Sap Carbon Sink (Cambodia), California's Carbon Sink, Cerrado Carbon Sink (Brazil), Victoria Carbon Sink (Australia), Great Dismal Swamp</i>                                                    |
| 7            | 10 min   |                                                                                     | <b>SHARE SMALL-GROUP MODELS</b><br>Students share their models with peers for feedback.                                                                                       | P-S   | <i>Peer Feedback Guidelines</i> , 3x3 sticky notes (green), 3x3 sticky notes (yellow), Community Agreements                                                                                                                                                                    |
| 8            | 5 min    |  | <b>REVISE SMALL-GROUP MODELS</b><br>Revise small-group models based on peer feedback.                                                                                         | T-U   | <i>Peer Feedback Self-Assessment</i>                                                                                                                                                                                                                                           |
| 9            | 15 min   |                                                                                     | <b>ESTABLISH CONSENSUS ON CONDITIONS THAT MAKE CARBON SINKS LIKELY TO BURN</b><br>Come to consensus on conditions that make carbon sinks more likely to burn and its effects. | V-X   | small-group models, <i>Making Sense Key</i> , <i>Sample Models</i> , chart paper, chart paper markers                                                                                                                                                                          |

| Part | Duration |  | Summary                                                                     | Slide | Materials                                                 |
|------|----------|--|-----------------------------------------------------------------------------|-------|-----------------------------------------------------------|
| 10   | 5 min    |  | <b>UPDATE PROGRESS TRACKER</b><br>Ask students to update Progress Trackers. | Y     | <i>Fires Progress Tracker</i>                             |
| 11   | 5 min    |  | <b>NAVIGATE</b><br>Review and add questions to the Driving Question Board.  | Z-AA  | 3x3 sticky notes, Driving Question Board, colored markers |

*End of day 2*

## Lesson 7 • Materials List

|                  | per student                                                                                                                                                                                                                                                               | per group                                                                                                                                                                                                                                                                                                                                                                                                                                                       | per class                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson materials | <ul style="list-style-type: none"> <li>science notebook</li> <li><i>Making Sense of Case Studies</i></li> <li><i>Peer Feedback Guidelines</i></li> <li><i>Peer Feedback Self-Assessment</i></li> <li>small-group models</li> <li><i>Fires Progress Tracker</i></li> </ul> | <ul style="list-style-type: none"> <li><i>Tonlé Sap Carbon Sink (Cambodia)</i></li> <li><i>California's Carbon Sink</i></li> <li><i>Cerrado Carbon Sink (Brazil)</i></li> <li><i>Victoria Carbon Sink (Australia)</i></li> <li><i>Great Dismal Swamp</i></li> <li>access to internet-connected device for students reading <i>California's Carbon Sink</i></li> <li>chart paper</li> <li>chart paper markers</li> <li>Group models from case studies</li> </ul> | <ul style="list-style-type: none"> <li>Ideas for Investigations and Related Phenomena posters from Lessons 1 and 6</li> <li><i>Sample Models</i></li> <li>3x3 sticky notes (green)</li> <li>3x3 sticky notes (yellow)</li> <li>Community Agreements</li> <li><i>Making Sense Key</i></li> <li>chart paper</li> <li>chart paper markers</li> <li>3x3 sticky notes</li> <li>Driving Question Board</li> <li>colored markers</li> </ul> |

### Materials preparation (20 minutes)

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

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

Be sure your Community Agreements are visible for reference during this lesson.

Day 1:

- Three-hole-punch all handouts so they can be added to student notebooks.
- Make copies of *Tonlé Sap Carbon Sink (Cambodia)*, *California's Carbon Sink*, *Cerrado Carbon Sink (Brazil)*, *Victoria Carbon Sink (Australia)* and *Great Dismal Swamp* so that students can write on them, take notes while reading, and respond to the questions. Groups of 3-5 students will choose one article to read. Make sure the class as a whole reads at least 4 of the 5 case studies. Print enough so that you have one case study per student.
- Groups reading *California's Carbon Sink* will need access to an internet-connected device.
- Copy *Making Sense of Case Studies* for every student.
- Gather chart paper and chart paper markers or equivalent.
- Make sure the Ideas for Investigations and Related Phenomena posters from Lesson 1 are visible.

Day 2:

- Get two colors of 3x3 sticky notes for students to use during peer review of group models.
- Gather chart paper and chart paper markers or equivalent.

## Lesson 7 • Where We Are Going and NOT Going

### Where We Are Going

In Lesson 6, students put together the pieces to explain the zombie fire system in the Arctic. In this lesson, students investigate case studies from around the world where other carbon sinks are burning and develop models to explain how and why those carbon sinks are likely to burn.

Students build toward a complete understanding of the following HS DCI:

*LS2.B: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.*

Students continue to use the science practices *developing and using models* and *obtaining, evaluating, and communicating information*, as well as the crosscutting concept *energy and matter*, as they have in previous lessons in this unit. In this second lesson set, the focal scale changes, moving from photosynthesis and cellular respiration at the cellular or organismal level in the Arctic ecosystem to developing and using models that show the flow of matter and energy within new ecosystems and between those systems and the biosphere and atmosphere.

Students consider how historical decisions led to changes that made each location more likely to burn and burn more intensely. Providing historical background is meant to motivate students to ask questions about how human actions might reverse these vulnerabilities. Many of the ecosystems they will encounter contain plants that are fire-tolerant or require fire but cannot withstand the intensity of current fire conditions. They will figure out more about these ways to reverse the frequency and severity of fires through management actions explored in Lessons 10 and 11.

Students encounter the terms *fire suppression*, *biosphere*, and *atmosphere*, which they should add to their Personal Glossaries. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

### Where We Are NOT Going

Although drought and increasing temperature changes are identified as conditions that create vulnerabilities to carbon sinks, climate change is not co-constructed until Lesson 9. Climate change involves long-term shifts in temperatures and weather, but weather and the mechanism for this phenomenon will not be explored to answer this lesson's questions.

Although drought is mentioned as one cause of increased vulnerability and intensity of fires, the unit will not address how climate change causes changes to global precipitation patterns.

There are complex histories that lead up to all of the events that occur in each case study presented. However, the lesson does not ask students to pursue all of the details behind government policies and decisions involved. Students interested in pursuing more details about the human actions discussed should be encouraged to read more from the references provided at the end of each case study.

# LEARNING PLAN for LESSON 7

## 1 · NAVIGATE

5 min

**MATERIALS:** science notebook, Ideas for Investigations and Related Phenomena posters from Lessons 1 and 6

**Review what we figured out.** Facilitate a class review of the last lesson. Display **slide A**. Use the prompts below to guide a brief discussion.

| Suggested prompt                                                                 | Sample student response                                                                                                                                                                                                                                                                                                                                                                  |
|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What did we figure out about matter and energy in the zombie fire system?</i> | The energy/fuel is matter in peat/permafrost trapped in the ice.<br><br>Once it thawed, temperatures increased and oxygen was able to get in so that carbon was available as matter and chemical energy to burn.<br><br>Since there were so many years that the matter and energy were built up and then trapped in the ice, this made it a carbon sink that could burn for a long time. |
| <i>How do you feel as we investigate these fires?</i>                            | Accept all responses.                                                                                                                                                                                                                                                                                                                                                                    |

### ADDITIONAL GUIDANCE

Gauge how much time students may need to process their feelings about zombie fires given their responses to the Social and Emotional Learning: Check, Reflect, Connect in *Zombie Fire Explanation*.

Be mindful that discussing wildfires can bring up past or recurring trauma for students. However, not all students will associate the class content with trauma, and it is important not to make assumptions about students' emotional states, experiences, or feelings. Help students become aware of both their own social emotional health and that of others. Additional suggestions for supporting students are found in *Teacher Background Knowledge*.

The feelings wheel on **slide A** is based on the work by Rosenberg, M. B. (2015). *Nonviolent communication: A language of life: Life-changing tools for healthy relationships*. PuddleDancer Press.

**Recall investigation ideas.** Display **slide B**. Ask students to recall some of the investigations they proposed to answer more of their questions. Make sure the Ideas for Investigations and Related Phenomena Posters are visible at this time.

| Suggested prompt                                                                                                                                                                                                                                                                                                                               | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><i>I heard you say there is a lot of carbon and energy locked in the permafrost/peat in the Arctic, and conditions like increasing temperature make that carbon sink more likely to burn. What new questions did we have?</i></p> <p><i>What investigations did you suggest to help us figure out more about fires in other places?</i></p> | <p>Are there other carbon sinks made of plants?</p> <p>Are other places with lots of plants burning?</p> <p>Are there other kinds of fires like the zombie fires happening but with different sources of matter and energy?</p> <p>Are there places where more or worse fires are happening?</p> <p>How can we help make this better?</p> <p>Look at the news for reports of fires.</p> <p>Ask scientists who study fires what is happening in other places.</p> <p>Look for other ecosystems with plants or other matter or something like peat that has lots of carbon-based molecules that can burn.</p> <p>Investigate other places in the world to find out if we see increased temperatures like we saw in the Arctic.</p> <p>Look at satellite images for fires around the world.</p> <p>Travel to different places and look for smoke.</p> |

**Review what we have figured out about carbon sinks.** Display **slide C**. Say, *It seems like we are curious about fires in other places in the world. What types of places would you expect to find large fires?* Listen for students to mention forests, prairies, other places with peat. Ask what those areas would have in common in terms of carbon (matter) and energy. Listen for students to mention large amounts of carbon (matter) and energy in carbon sinks where there is a build-up of plants or other plant-like material. If they do not bring up carbon sinks, prompt them to look at their Personal Glossaries from Lesson 3.

Display **slide D**. Say, *Turn to your partner and remind each other what we mean when we say “carbon sink.” Feel free to review your science notebook and Personal Glossary. Then we will share as a class.*

| Suggested prompt                                       | Sample student response                                                                                                                                                                                                                       |
|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><i>What do we mean when we say carbon sink?</i></p> | <p>Someplace (like the peat in the Arctic) with lots of plants or carbon stored.</p> <p>A place with large amounts of energy transferred from the Sun to plants.</p> <p>If the carbon is in the carbon sink, it is not in the atmosphere.</p> |



| Suggested prompt                                    | Sample student response                                                                                                                                                         |
|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>How do we find those carbon sinks and fires?</i> | <p>Locate places on Earth that have forests, peat, grassland, or other plant-based ecosystems.</p> <p>Look for fires on the news.</p> <p>Look at satellite images of smoke.</p> |

## 2 · EXPLORING GLOBAL WILDFIRES

7 min

MATERIALS: None

**Interpret global fire map.** Display **slide E**. Say, *Scientists track if and where fires happen around the world. Let's take a look at if and where fires are happening to see if there are other carbon sinks that would be useful to investigate.* Direct students to make a Notice and Wonder chart in their science notebooks.

Display **slide F**. Play the embedded animation <https://youtu.be/NG2WMjDfjDk> and call out dates to students as months pass by. Let the animation play once. Give students 30 seconds to record noticings and wonderings on their own. Then have students turn and talk with a partner about what they observed. Play the animation a second and perhaps a third time to allow more time to notice patterns and record what they see. Suggest students shift their focus to different parts of the map and look for different patterns each time it plays.

Bring the class together and have them share what they noticed and wondered about the animation. Support students in identifying the names of locations on the map. Encourage them to point to the region where they saw fires if they do not know the name to let peers support them in identification.

Listen for responses such as:

- We notice that a lot of these fires are happening in the Arctic, coastal Australia, Central Africa, the Western and Southeastern US, the Amazon/South America, and Southeast Asia.
- We notice as snow cover goes away in the Northern Hemisphere, fires appear in the Arctic regions.
- There seem to be a lot of fires burning in the middle along the equator.
- Fires seem to appear in different parts of the world at different times of the year.
- We wonder if this pattern happens every year.

**Speculate about what is happening at other fire locations.** Display **slide G**. Say, *We already investigated fires in the Arctic. Discuss the prompts below as a class.*

| Suggested prompt                                                               | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What do you think is happening in these other places that causes fires?</i> | <p>People are starting fires.</p> <p>People create conditions that make the fire more likely to burn.</p> <p>These are places where there is a lot of carbon (fuel) to burn.</p> <p>Bad storms with lots of lightning.</p> <p>Less rain than normal, so plants are dry.</p> <p>It is getting hotter, and fires start more easily.</p>                                                                                                                                      |
| <i>What would be in these places that act as carbon sinks?</i>                 | <p>Trees.</p> <p>Forests.</p> <p>Peat.</p> <p>Grass.</p> <p>Oil.</p>                                                                                                                                                                                                                                                                                                                                                                                                       |
| <i>How can we find out what is burning in these locations and why?</i>         | <p>We can do research about each location.</p> <p>Read, watch videos, talk to an expert.</p>                                                                                                                                                                                                                                                                                                                                                                               |
| <b>ADDITIONAL GUIDANCE</b>                                                     | <p>If students are curious to further investigate fire locations or frequency, data and animations from other years are available from the Copernicus Atmosphere Monitoring Service: <a href="https://atmosphere.copernicus.eu/global-fire-monitoring">https://atmosphere.copernicus.eu/global-fire-monitoring</a>. In Lesson 10 students will investigate case studies about successful fire management, and in Lesson 11 they will design fire management solutions.</p> |

### 3 · INVESTIGATE CASE STUDIES OF CARBON SINK FIRES

15 min

**MATERIALS:** *Making Sense of Case Studies*, Tonlé Sap Carbon Sink (Cambodia), California's Carbon Sink, Cerrado Carbon Sink (Brazil), Victoria Carbon Sink (Australia), Great Dismal Swamp, access to internet-connected device for students reading *California's Carbon Sink*

**Introduce the case studies.** Display slide H. Explain that you have five case studies that include photographs and data collected from the different locations they identified on the map that present ideas about carbon sinks that are burning around the world: Western United States (California), Southeastern United States (Great Dismal Swamp), Australia (Victoria), Brazil (the Cerrado), and Cambodia (Tonlé Sap Lake). \*

#### \* ATTENDING TO EQUITY

The case studies are written at similar reading levels and contain equally rigorous scientific information. However, they vary in length and complexity of graphical data and historical ideas. You may wish to allow students to select readings based on interest before dividing them into groups. At your

## ALTERNATE ACTIVITY

If there is another region you believe would generate higher interest for your students, create additional case studies, including at least two of the following criteria:

- A carbon sink that has a higher risk, frequency, or intensity of fire due to changes in weather patterns.
- A carbon sink with higher risk, frequency, or intensity of fire due to human activity and decision-making.
- Fire suppression policies that build an increasing fuel load in the carbon sink.

Helpful resources include:

- <https://www.fire.ca.gov/>
- <https://firms.modaps.eosdis.nasa.gov/map/#d:24hrs;@0.0,0.0,3z>
- <https://www.copernicus.eu/en/european-forest-fire-information-system>
- <https://www.fs.usda.gov/managing-land/fire>

**Focus on social and emotional learning.** Display slide I. Say, *During this investigation you might encounter information that brings up different feelings and feelings with varying intensity. This is normal, and we want to monitor how we feel and react. We need to be mindful that all parts of these systems deserve respect and commit to that. Be aware of how your social emotional reactions impact your participation. All feelings and intensity of feelings are valid.*

**Introduce the impact of power and historicity.** Display slide J. Say, *In OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit) and in Lesson 1 of this unit we worked with the Five Dimensions of Complex Systems that gave us opportunities to consider the roles of humans and nonhumans in systems in shaping ecosystems. These help us think of humans in the system alongside all of the other factors instead of them all simply being available for our use.* Explain that all of these dimensions are impacted by power and historicity, which run vertically on the slide image.

Ask students to share some examples where a historical decision made by people in power impacted species or places over the long term. They may remember examples from forming conservation areas in *Serengeti Unit*. For example, European colonizers decided to protect the Serengeti and tried to remove all of the people living there from the park boundaries. No people live within the National Park boundaries, but people can live in many of the reserves around the park because they changed the boundaries. There are restrictions on what people can and cannot do in these areas. This protected many of the animals, but it left problems for people trying to move from one place to another to get to resources they need. The debate over the highway through the Serengeti was a continuation of the power struggle between groups of people in that region and for whom or what it should be used.

discretion, you can assign students to intentional, mixed-ability reading groups, with the students who need more reading support along with students who do not need the extra support. Providing students with the opportunity to choose the level of perceived challenge can support engagement and help develop self-determination, pride in accomplishment, and increase the degree to which they feel connected to their learning. *Tonlé Sap Carbon Sink (Cambodia)* and *Cerrado Carbon Sink (Brazil)* are the most complex, followed by *Great Dismal Swamp* and *Victoria Carbon Sink (Australia)*. *California's Carbon Sink* is the most accessible to all reading levels and also has an accompanying video to help build background knowledge.

## \* ATTENDING TO EQUITY

### Supporting emergent multilingual students:

Encourage students to record their ideas using linguistic (e.g., written words) and nonlinguistic modes (e.g., photographs, drawings, tables, graphs, mathematical equations, measurements). This can also include words and symbols from their home language. This is especially important for emerging multilingual students because making connections between written words and nonlinguistic representations helps students generate richer explanations of scientific phenomena. Additionally, if students have lived or traveled to other countries, invite them to relate these case studies to their lived experiences.

## \* SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

As students interact with their case studies, they critically read scientific literature that has been adapted for classroom use with the goal of summarizing complex information in simpler but accurate terms. As students develop and/or use this practice, encourage them to paraphrase rather than copying down information verbatim from the case

## ADDITIONAL GUIDANCE

The Learning in Places Collaborative defines power and historicity in the following way:

- “Power is ubiquitous in social systems, and how power is understood has consequential impacts on what is seen as important to act on. Power is not inherently good or bad, rather it is a question of how it is utilized and why.” Both systemic power and individual and/or collective agency should be considered.
- “Historicity refers to cultural perceptions of the past; the principles, experiences, and values that shape these perceptions; and how historicized practices, tools, and information continually and consequently shape the present and future.”

As students read each case study, they will consider the different historical decisions or actions made by groups with or without power that impact the current condition of the carbon sink that is burning and decisions about how to care for the remaining carbon sink. The final question on *Making Sense of Case Studies* is meant to inspire hopeful questions and ideas for what could be done to prevent or reduce the intensity and frequency of future fires. Management strategies will be discussed in more depth in Lessons 10 and 11.

Additional examples of power and historicity for students unfamiliar with *Serengeti Unit* may include decisions that created segregated cities, forced removal of First Nations from their homelands, or expansion of a city into farmland or a wildlife area.

Learning in Places Collaborative. (2021). Framework: Power and Historicity. Bothell, Seattle, WA & Evanston, IL: Learning in Places. [http://learninginplaces.org/wp-content/uploads/2021/10/framework\\_power-and-historicity\\_rev10142021.pdf](http://learninginplaces.org/wp-content/uploads/2021/10/framework_power-and-historicity_rev10142021.pdf)

**Introduce the Making Sense questions.** Display slide K. Distribute *Making Sense of Case Studies* to each student. Explain that students should answer these questions as they read their case studies. Say, *The questions in this handout will help us think about what causes carbon sinks to be more likely to burn in multiple ways. We will look at carbon (matter) and energy as it moves through each system, but we will also figure out more about important historical events and decisions people made that changed the ecosystem in what could be considered positive or negative ways, depending on your perspective. Think about the long-term impacts of those decisions and use the last 2 questions to think about what actions people could take going forward if they want to reduce the frequency or severity of the fires.* \*



**Read case studies in groups.** Display slide L. Divide your class into groups of 3-5 students, each focused on one case study. Allow each of those groups to choose one case study, but make sure at least four different case studies are chosen by the class overall. Say, *Each group will read one case study. Answer the Making Sense questions as a group.* Distribute *Tonlé Sap Carbon Sink (Cambodia)*, *California's Carbon Sink*, *Cerrado Carbon Sink (Brazil)*, *Victoria Carbon Sink (Australia)* or *Great Dismal Swamp* to each student, or provide students with a digital copy. If students are using a paper copy, encourage them to mark it up using whatever reading strategy is in place in your classroom. Have students complete *Making Sense of Case Studies* with their group. \*\*

study with prompts such as, *How can you say that in your own words? or Is there a simpler way to say that?*

## \* SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

Students should use this crosscutting concept to help make sense of the idea that carbon sinks are the result of the accumulation of matter and energy over a long period of time. One reason is that the flow of matter and energy has been prevented by fire suppression. As droughts intensify and temperatures increase, the organic material in the sinks is drier and more likely to burn intensely if ignited, which can transfer large amounts of matter and energy out of the system.

## ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** Evidence of complex ideas from reading each case study (SEP: 8.1), such as:

- The role of photosynthesis and cellular respiration in the movement of carbon in the biosphere and between the biosphere and atmosphere. (DCI: LS2.B.3; CCC: 5.2)
- How changes in the system result in a build-up of carbon and energy that could burn. (DCI: LS2.B.3; CCC: 5.2)
- The movement of carbon and energy from the biosphere to the atmosphere after/during a fire. (DCI: LS2.B.3; CCC: 5.2)

**What to do:** Circulate around the room and listen to small-group discussions. Collect *Making Sense of Case Studies* as an artifact after students finish making their initial group models. Use *Making Sense Key* to evaluate student responses. Ask students to remind you of what they figured out about the role of decomposers in Lesson 3, the role of photosynthesis in the movement of energy and matter in the ecosystem in Lesson 4, and the Gotta-Have-It Checklist or explanation from Lesson 5 for the energy and matter flow in the peat/permafrost system. Provide them with an opportunity to also consult their Progress Trackers and other resources in their science notebooks to revise their answers. Ask what decisions people made that made the carbon sink more likely to burn. Ask if any of those changes could be reversible.

**Building toward 7.A** Critically read scientific literature adapted for classroom use to obtain information and summarize complex ideas about how changes to carbon sinks in ecosystems affect how matter and energy are exchanged between components of the system. (SEP: 8.1; DCI: LS2.B.3; CCC: 5.2)

## 4 · DEVELOP SMALL-GROUP MODELS OF CARBON SINK ECOSYSTEMS

13 min

**MATERIALS:** science notebook, chart paper, chart paper markers, *Sample Models*

**Develop small-group models.** Display slide M. Say, *How can you create an initial model for your case study that explains: How and why are carbon sinks in this ecosystem likely to burn? Think about the components, interactions, and mechanisms that cause the burning. Be sure to include answers to these questions in your model as well:*

- *What makes this a carbon sink?*
- *What conditions make the matter and energy more likely to burn in this ecosystem?*
- *What role do power and historicity play in the scenario?*
- *What are the potential effects from burning this carbon sink?*

As students work in their groups, ask them to record any questions they have in their science notebooks. Listen for students to ask questions about fires in other places around the world relevant to them or local to where they are. Save the small-group models to revisit in the next class. Allow students to make any revisions to *Making Sense of Case Studies* as they work on their models. Collect *Making Sense of Case Studies* and provide feedback using the *Making Sense Key* before day 2.

Sample models for each case study are provided on *Sample Models*. Note these demonstrate only one possible representation of each case study.

## 5 · NAVIGATE

5 min

MATERIALS: None

**Check in with how students are feeling.** Display **slide N**. Say, *As I mentioned earlier, learning about the impacts of these fires and the historical events that led up to them may bring up feelings for you. I want to give everyone a chance to do a social and emotional check-in about these case studies.* Encourage students to take a few minutes to turn and talk with a trusted peer, write independently in their science notebooks, or think about how they feel about the case studies. They can use the feelings wheel from *Feelings Wheel* to help them identify or name an emotion. Encourage them to talk to you or another trusted adult if you notice they have feelings they want to share about what they read. \*

### \* ATTENDING TO EQUITY

The effects of wildfires and burning carbon sinks are disproportionately experienced by BIPOC (Black, Indigenous, People of Color) communities globally.

Deforestation has severe consequences for Indigenous communities, which often have strong connections to the land and depend on ecosystems for their livelihoods. Deforestation, fire, and changes in land use displace BIPOC populations, impact cultural heritage spaces, and create losses of traditional ways of knowing for many people. These communities may face health issues, such as respiratory problems, higher rates of asthma, and other adverse health effects due to exposure to pollution from burning carbon sinks. Additionally, these communities may face challenges adapting to new environments, finding shelter, and accessing resources, thereby increasing their vulnerability to further marginalization. As an extension, consider having students research ways to support Indigenous rights, climate advocacy, and making sustainable choices to begin addressing some of the harm done to communities.

End of day 1

## 6 · NAVIGATE

5 min

MATERIALS: *Making Sense of Case Studies*, Group models from case studies, *Tonlé Sap Carbon Sink (Cambodia)*, *California's Carbon Sink*, *Cerrado Carbon Sink (Brazil)*, *Victoria Carbon Sink (Australia)*, *Great Dismal Swamp*

**Review group models from case studies.** Distribute *Making Sense of Case Studies* with your suggestions to each student. Display **slide O**. Ask students to review your feedback and then gather with their group and their group model. Small groups should share feedback and make small revisions or notes about where they want help, following the prompts on the slide.

## 7 · SHARE SMALL-GROUP MODELS

10 min

**Introduce model-sharing activity.** Display slide P. Say, *In the last class you all developed models explaining how and why different carbon sinks in ecosystems are likely to burn. I noticed that not all of the groups modeled their systems in the same way. Let's spend some time hearing from one another about these different cases. You will explain your model to other groups to share why the ecosystem in your case study is more likely to burn. We will provide one another with feedback to help each group improve how the models explain the points described on the slide.*

**Reflect on Community Agreements.** Say, *Before we do that, let's briefly revisit our Community Agreements.* Display slide Q or display your Community Agreements, and discuss categories related to supporting one another and moving their science forward. Remind students that developing models that explain energy and matter in these complex systems can be challenging. Work to develop a supportive space where students feel comfortable making mistakes, receiving feedback, and working to improve their explanations. Say, *Later in the lesson, I am going to ask you to name one student who helped push your thinking forward. I will share those shoutouts with you at later points in the unit (in Lesson 8). Take a half minute to think about what you want to try to do in the many discussions we will have over the next two days as a whole class as well as in small groups and with partners that could really help push your thinking and the thinking of others forward.\**

**Review the feedback document.** Display slide R. Distribute *Peer Feedback Guidelines* to each student. Say, *Use Peer Feedback Guidelines to help you give and receive feedback from your peers as you circulate the room and hear about other groups' models. As you share, ask questions and provide feedback that helps the group focus on the flow of energy in the system, what makes it a carbon sink, and what conditions make it likely to burn.*

Talk through a few examples on the *Peer Feedback Guidelines* and encourage students to use these sentence starters when they provide feedback to other groups.

**Explain two stay, two stray sharing protocol.** Display slide S. Explain that two people in each group will stay with the model to explain it and listen to and record feedback (positive and critical). The two group members who stray will visit other models to hear about and provide feedback on models from at least two teams that read different case studies. As they stray, they should use *Peer Feedback Guidelines* to provide constructive feedback. Have these students take two different-colored sticky notes with them as they look at other models. They will use one color to leave feedback and the other color will be used to bring ideas back to their group. For example, they may see a representation that helps them understand the flow of energy and matter, or what they see might remind them of something their group forgot to include. Suggest that students record similarities and differences in the ecosystems they hear about or in ways other groups represent what is happening in their ecosystem.

#### ADDITIONAL GUIDANCE

One option for the two group members who stay with the model is for one person to take the role of speaker, who explains the model while the other person takes the role of recorder, who takes notes about the feedback they are given. Students can switch roles each time they interact with a new group. Both students should participate in discussing feedback from other groups to practice how to constructively discuss ideas.

This step uses a modified version of the Sticky Note Feedback Tool for Students by the Tools for Ambitious Science Teaching. For complete protocol, visit their website at <https://ambitiousscienceteaching.org/sticky-note-student-feedback/>.

#### \* ATTENDING TO EQUITY

Making time in subsequent lessons for public celebration of specific student contributions that are recognized and valued by their peers is one way to measure progress toward the Community Agreement of being equitable. The same strategy can be used to reinforce the Community Agreement of being committed to our community.



## 8 · REVISE SMALL-GROUP MODELS

5 min

MATERIALS: *Peer Feedback Self-Assessment*

 **Revise small-group models.** Display slide T. Explain that students will now have an opportunity to revise their models. Say, *Now you will go back to your groups to revise your model. Talk with your group about what feedback you will use and why.* Each group member should briefly share the feedback received and ideas gained from visiting other models and discuss then revise their models. Remind students to focus on how the feedback they received helps clarify what happens to the matter and energy in their systems and how it makes the carbon sink more likely to burn. Groups should make sure each person is ready to contribute to the whole-class discussion that follows.

### ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** Models with components, interactions, and mechanisms (SEP: 2.3) that include:

- Energy from the Sun and matter from carbon dioxide in the atmosphere flowing to plants through photosynthesis. (DCI: LS2.B.3; CCC: 5.2)
- Carbon (matter) from plants flowing to animals/decomposers and to the atmosphere through cellular respiration. (DCI: LS2.B.3; CCC: 5.2)
- Energy and matter (carbon) from plants burning and flowing to the atmosphere as light, heat, and carbon dioxide. (CCC: 5.2)
- Factors that contributed to reduced flow of carbon (matter), resulting in build-up of carbon sink in the biosphere. (DCI: LS2.B.3; CCC: 5.2)

**What to do:** During small-group work, circulate around the room. Prompt students to think about:

- The inputs and outputs of the system.
- How energy and matter change in the system.
- Mechanisms that transfer matter and energy with or without fire.
- Biological and atmospheric level changes.

If students struggle to identify any of these components, interactions, and mechanisms, refer them to *Making Sense of Case Studies*. As groups develop and revise their models, track which students are contributing to discussions on a clipboard as you walk around and listen. Consider calling on students you did not hear contribute when moving to the consensus discussion.

**Building toward 7.B** Develop, revise, and use a model to explain how energy and matter flow between the biosphere and atmosphere through biological processes and fire. (SEP: 2.3; DCI: LS2.B.3; CCC: 5.2)

**Self-assess peer feedback.** Display slide U. Say, *Collaboration is important in the figuring-out process, and reflection on how we give and receive feedback can help us become better collaborators. Scientists often work in teams and collaborate with colleagues to answer questions. Learning to give and especially receive critical feedback in a productive way takes practice. Complete Peer Feedback Self-Assessment to reflect on your strengths and areas for growth in this experience with peer feedback and the contributions of your classmates towards our focal agreement of Moving science thinking forward.* Collect *Peer Feedback Self-Assessment* from each student and review. Follow up with students who may need additional support—including those who check “no” frequently or who cannot find a way to do better next time. Create a list of who students name as contributing to their learning and recognize those people on a slide or verbally in the next class.



9 · ESTABLISH CONSENSUS ON CONDITIONS THAT MAKE CARBON SINKS LIKELY TO BURN

15 min

MATERIALS: science notebook, small-group models, *Making Sense Key*, *Sample Models*, chart paper, chart paper markers

**Establish consensus on conditions that make carbon sinks likely to burn.** Have students bring their group models, notebooks, and pencils to join a Scientists Circle. Display **slide V**. Say, *Let's share what we figured out from these case studies to see what they have in common to come to a consensus on a list of conditions that make carbon sinks more likely to burn.* Start by asking each group to briefly describe their carbon sink and why it is likely to burn. Then ask students, especially those who strayed during the peer review, to discuss some of the similarities they see between case studies that will help the class develop a list of conditions that make a carbon sink likely to burn. As students share their ideas, begin to create a list on chart paper titled: *What makes a carbon sink more likely to burn?* Use *Making Sense Key* and *Sample Models* as guides during the discussion.

| Suggested prompt                                                                   | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What conditions make the carbon sinks you investigated more likely to burn?</i> | <p>Many ecosystems were hotter than usual.</p> <p>Many ecosystems were drier than usual.</p> <p>They built dams on the Mekong River, so Tonlé Sap Lake started drying out.</p> <p>George Washington, timber, and railroad companies drained the Great Dismal Swamp.</p> <p>People set fires to clear land for agriculture in the Cerrado.</p> <p>The government put policies in place that suppressed fires in California, Australia, and the Cerrado. There was more fuel available to burn.</p> <p>Colonists killed Indigenous people in California and Australia and stopped cultural burning. Bigger trees grew in, and there was more fuel around to burn.</p> <p>Many were near the equator or in very sunny locations where there was a lot of solar energy to make a lot of plant matter.</p> |

| Suggested prompt                                                                         | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What patterns did you notice in the carbon (matter) and energy in each ecosystem?</i> | <p>All of these ecosystems have carbon sinks with large amounts of plant material where there is more stored carbon and energy than is being used by this system.</p> <p>Several ecosystems are in places where it is sunny for large portions of the year.</p> <p>Ecosystems are drier than usual because they were drained or because of heat and drought.</p> <p>More carbon moves from the biosphere into the atmosphere in each case than before.</p> <p>There was more carbon and energy fuel in the ecosystem available to burn today than there would have been in the past because fires were suppressed.</p> <p>Carbon and energy cycle between the biosphere and atmosphere.</p> |

#### ADDITIONAL GUIDANCE

Use the terms *biosphere* and *atmosphere* for generalizing the locations on each group model. Students will likely have experience with these terms from prior grade bands and their lived experiences (5-ESS2.A.1, MS ESS2.D). The biosphere includes living things, including humans, and the atmosphere is the mixture of gasses surrounding the Earth. If useful, suggest students add these terms to their Personal Glossaries.

**Discuss consequences and possible solutions.** After the class finishes the list of conditions, display **slide W** and facilitate a discussion of the consequences that occurred in each case study. Ask students to share some of the ideas they came up with to better protect their carbon sinks from burning.

| Suggested prompts                                             | Sample student responses                                                                                                                                                                     | Follow-up questions                                                                                                                                                                                                              |
|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What are the consequences when these conditions exist?</i> | <p>Very large fires.</p> <p>People lose property or a way of life.</p> <p>Animals lose their homes.</p> <p>Lots of carbon dioxide is released into the atmosphere.</p> <p>Lots of smoke.</p> | <p><i>What happens in the ecosystem when fires burn?</i></p> <p><i>Where does all the energy and matter go when the fires burn?</i></p> <p><i>How are human and nonhuman components of the system affected by the fires?</i></p> |

| Suggested prompts                                                                  | Sample student responses                                                                                    | Follow-up questions                                     |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| <i>What ideas did you have for possible solutions to protect the carbon sinks?</i> | Bring back cultural burning.<br>Stop people from moving into the forests.<br>Stop building dams and canals. | <i>What could prevent the carbon sink from burning?</i> |

**Update Personal Glossaries.** When students bring up fire suppression during discussion, take time to have students add the definition of this term to Personal Glossaries. Many students will have encountered this term in their case studies. Encourage students to share what they encountered about fire suppression in different contexts to build a common definition. Display **slide X** and add the term to their Personal Glossaries.

#### ADDITIONAL GUIDANCE

Fire suppression as a policy is used in two ways: 1) It instructs governments to put out all small fires caused by lightning or ignition sources and 2) also bans the use of intentional, human-set prescribed burns that would reduce the amount of biomass available. Prescribed burns often clear out dead underbrush or dead grass from a previous season. When fire suppression occurs, the size of the ecosystem's carbon sink grows.

## 10 • UPDATE PROGRESS TRACKER

5 min

**MATERIALS:** *Fires Progress Tracker*

**Update Progress Tracker.** Display **slide Y**. Say, *What are the key takeaways that we figured out in the lesson that we need to keep track of? In the questions column, consider adding ideas you may wonder about for solving the problems we are seeing with fires in these ecosystems or other related phenomena. Are there actions people could take that you are curious to learn more about? Complete a new row in Fires Progress Tracker. One possible representation of a completed Progress Tracker is shown below.*

|                                                             | What we figured out (WWFO)                                                                                                                                                                                                                                                                                                                         | How does WWFO help us make progress on our Driving Question about zombie fires?                                                                                                                                        | How does WWFO connect to me or my community or have a larger-scale impact?                                                                                                                                                                                                                                                                                           | What questions do I have now?                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Lesson 2: What is peat and why does it burn so much?</b> | <p>-Many different ecosystems have carbon sinks that result from the flow of energy and matter from the Sun.</p> <p>-There are common factors in ecosystems that reduce the flow of energy and matter and create carbon sinks more likely to burn..</p> <p>-Fire increases the flow of matter and energy from the biosphere to the atmosphere.</p> | <p>There must be a really delicate balance between where matter and energy are in a system to make sure that it does not become more likely to burn. People's historical decisions impact what is happening today.</p> | <p>We had bad fires in our community last year. I wonder if we made them worse because there were homes in the forest there.</p> <p>I want to know about the consequences for me if these places burn. Is there a lot of carbon dioxide released related to climate change?</p> <p>I'm not really sure how these fires in other parts of the world matter to me.</p> | <p>-How much carbon dioxide is released when these carbon sinks burn?</p> <p>-Do these fires contribute to climate change?</p> <p>-What can be done to stop all of this burning?</p> <p>-Could we bring back Indigenous burning practices?</p> <p>-Should the government stop the fire suppression policies?</p> <p>-Are there any carbon sinks near me that could burn? How can we protect them?</p> |

## 11 · NAVIGATE

5 min

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

**Add questions to the DQB.** Display slide Z. Say, *So we now understand some of the places where carbon sinks are burning around the world and what is making them more likely to burn. What new questions do you have?* Provide sticky notes for students to write new questions. Ask them to share questions out loud as they add them to the DQB. Listen for questions such as:

- How much carbon dioxide is released when these carbon sinks burn?
- Do these fires contribute to climate change?
- Why does it matter to me if these places burn?
- What can be done to stop all of this burning?
- Could we bring back Indigenous burning practices?
- Should the government stop the fire suppression policies?
- Are there any carbon sinks near me that could burn? How can we protect them?

**Turn and Talk.** Display slide AA. Say, *Based on what we figured out today, what do we need to figure out next? What do we need to do to investigate these questions?*

Listen for responses such as:

- How bad is all of that carbon dioxide in the atmosphere?
- What are the consequences of all of these fires happening in the world?

## Additional Lesson 7 Teacher Guidance

### **SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA**

**CCSS.ELA-LITERACY.RST.9-10.2** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

Students read an article together and piece together central ideas to create an explanation to share with the rest of the class.

# LESSON 8: Why should we be concerned that carbon sinks around the world are burning?

**PREVIOUS LESSON** We used case studies to investigate places, lands, and waters where global carbon sinks are burning with more frequency. We analyzed how energy and matter are moving through each system and discussed the historical events and decisions that contributed to the current conditions that make each carbon sink more likely to burn. We developed small-group models to help us come to consensus on the conditions that make carbon sinks more likely to burn. We wondered what the consequences and large-scale impacts are of fires from all of these ecosystems. We also wondered about ways to manage fires into the future.

## THIS LESSON

### INVESTIGATION

2 days



We investigate the effect of increased carbon dioxide on temperature with a bottle system designed to simulate fires in ecosystems. We develop directional hypotheses and collect evidence to support our hypotheses. We revise our hypotheses to explain the relationship between atmospheric carbon dioxide and temperature at the global scale and investigate data collected by scientists. We wonder how the relationship between carbon dioxide and temperature affects other systems.

**NEXT LESSON** We will use a quantitative model to simulate how carbon and energy flow through Earth's systems. We will develop a Gotta-Have-It Checklist and consensus model explaining the implications of rising carbon dioxide levels and temperatures on Earth's systems. We will decide to investigate ways to manage carbon sinks to reduce feedback effects from climate change in relation to fires.

## BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



## WHAT STUDENTS WILL DO

**8.A** Make a directional hypothesis to specify what happens to temperature (effect) when carbon dioxide concentrations in the atmosphere increase due to burning (cause). (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)

## WHAT STUDENTS WILL FIGURE OUT

- Increased carbon dioxide in the air causes increased air temperature.
- A directional hypothesis explains the effect of carbon dioxide concentration on temperature in a simulated system.
- Global data indicates the relationship we figured out in our investigation system is similar to the relationship at the global scale.

## Lesson 8 • Learning Plan Snapshot

| Part                | Duration |                                                                                     | Summary                                                                                                                                                                                                                            | Slide | Materials                                                                                                       |
|---------------------|----------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-----------------------------------------------------------------------------------------------------------------|
| 1                   | 3 min    |                                                                                     | <b>NAVIGATE</b><br>Revisit what we figured out in Lesson 7 to help set the stage for the lesson.                                                                                                                                   | A     | <i>Fires Progress Tracker</i>                                                                                   |
| 2                   | 7 min    |                                                                                     | <b>ORIENT TO THE CARBON DIOXIDE-TEMPERATURE INVESTIGATION</b><br>Prepare to investigate the effect of increased carbon dioxide levels on temperature by mapping the system and developing directional hypotheses.                  | B-G   |                                                                                                                 |
| 3                   | 5 min    |    | <b>DEVELOP DIRECTIONAL HYPOTHESES</b><br>Have students create a directional hypothesis to predict the relationship between carbon dioxide and temperature on <i>CO2 Temperature Investigation</i> .                                | H     | <i>CO2 Temperature Investigation</i>                                                                            |
| 4                   | 20 min   |                                                                                     | <b>CONDUCT CARBON DIOXIDE-TEMPERATURE INVESTIGATION</b><br>Investigate the effect of increased carbon dioxide levels on temperature.                                                                                               | I-L   | safety goggles, non-latex apron, nitrile gloves, Community Agreements, Carbon Dioxide-Temperature Investigation |
| 5                   | 7 min    |    | <b>MAKE SENSE OF THE CARBON-DIOXIDE TEMPERATURE INVESTIGATION</b><br>Work in small groups to make sense of the data collected in material: BO.L8.HO].                                                                              | M     | <i>CO2 Temperature Investigation</i>                                                                            |
| 6                   | 3 min    |                                                                                     | <b>NAVIGATE</b><br>Relate the evidence from the bottle system to make predictions about the relationship between carbon dioxide and temperature in an ecosystem.                                                                   | N     |                                                                                                                 |
| <i>End of day 1</i> |          |                                                                                     |                                                                                                                                                                                                                                    |       |                                                                                                                 |
| 7                   | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Revise <i>CO2 Temperature Investigation</i> based on feedback.                                                                                                                                                  | O     | <i>CO2 Temperature Investigation</i>                                                                            |
| 8                   | 10 min   |                                                                                     | <b>BUILDING UNDERSTANDINGS DISCUSSION</b><br>Facilitate a Building Understandings Discussion about the relationship between carbon dioxide concentration and temperature.                                                          | P     | <i>CO2 Temperature Investigation</i>                                                                            |
| 9                   | 5 min    |                                                                                     | <b>TURN AND TALK ABOUT GLOBAL TEMPERATURE AND CO2</b><br>Organize a Turn and Talk to relate the bottle system to the real world.                                                                                                   | Q     |                                                                                                                 |
| 10                  | 5 min    |  | <b>REVISE DIRECTIONAL HYPOTHESES FOR THE GLOBAL SYSTEM</b><br>Prompt students to review their original directional hypotheses to create a new one about the relationship between carbon dioxide and temperature on a global scale. | R     | <i>CO2 Temperature Investigation</i>                                                                            |
| 11                  | 15 min   |                                                                                     | <b>ANALYZE GLOBAL CARBON DIOXIDE DATA</b><br>Analyze a graph comparing changes in global carbon dioxide and temperature data.                                                                                                      | S-U   | <i>Global Temperature/CO2 Data</i>                                                                              |
| 12                  | 10 min   |                                                                                     | <b>NAVIGATE: UPDATE PROGRESS TRACKERS</b><br>Support students in updating their Progress Trackers.                                                                                                                                 | V     | <i>Fires Progress Tracker</i>                                                                                   |
| <i>End of day 2</i> |          |                                                                                     |                                                                                                                                                                                                                                    |       |                                                                                                                 |

## Lesson 8 • Materials List

|                                                    | per student                                                                                                                                                                                                                                                                                | per group                                                                                                                                                                                                                                                                                                                                                                                                                                                | per class                                                                              |
|----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Carbon Dioxide-Temperature Investigation materials | <ul style="list-style-type: none"> <li>• <i>CO2 Investigation Guide</i></li> <li>• <i>CO2 Temperature Investigation</i></li> <li>• safety goggles</li> </ul>                                                                                                                               | <ul style="list-style-type: none"> <li>• Two 16.9-oz plastic water bottles</li> <li>• two 1-inch balls of modeling clay to plug bottle and hold thermometer</li> <li>• 2 digital thermometers</li> <li>• 4 Alka-Seltzer tablets</li> <li>• 100-ml beaker</li> <li>• 200 ml water</li> <li>• a metric ruler</li> <li>• a heat lamp with a 250W bulb to share between groups</li> <li>• plastic wrap</li> <li>• 2 rubber bands</li> <li>• timer</li> </ul> | <ul style="list-style-type: none"> <li>• <i>CO2 Investigation Responses</i></li> </ul> |
| Lesson materials                                   | <ul style="list-style-type: none"> <li>• science notebook</li> <li>• <i>Fires Progress Tracker</i></li> <li>• <i>CO2 Temperature Investigation</i></li> <li>• safety goggles</li> <li>• non-latex apron</li> <li>• nitrile gloves</li> <li>• <i>Global Temperature/CO2 Data</i></li> </ul> |                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <ul style="list-style-type: none"> <li>• Community Agreements</li> </ul>               |

### Materials preparation (20 minutes)

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

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

Three-hole-punch all handouts to be added to student notebooks.

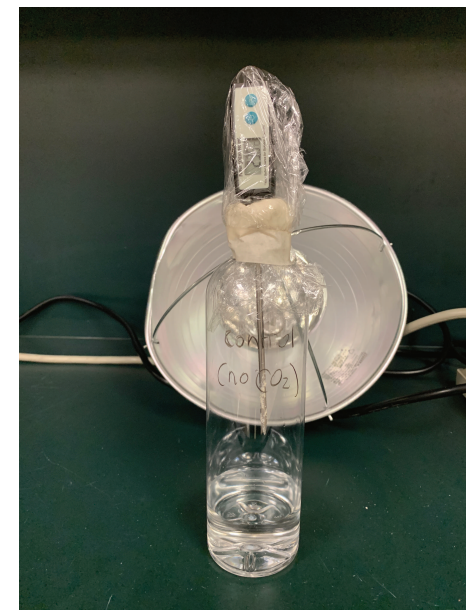
Be sure your Community Agreements are visible for reference during this lesson.

#### Day 1: Carbon Dioxide-Temperature Investigation

- **Group size:** Students work in groups of 4.
- **Setup:** Gather materials for the carbon dioxide investigation as described in *CO2 Investigation Guide*. Each heat lamp consists of a bulb, metal lampshade, electrical cord, and clamp. Set up each heat lamp near an electrical outlet in a position where the lamp is clamped onto something and pointing outward, as shown in the image. The crucial factor is that all bottles are equidistant from the lamp. You may have to test this setup in advance to find the ideal distance for your context.
- **Notes for during the investigation:** Each heat lamp will be plugged into an electrical outlet and will get hot during the course of the investigation. Ensure that each student assigned the role of heat lamp manager understands the important safety precautions described below. For additional information, see *CO2 Investigation Guide*.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. Students will be working with a heat lamp plugged into an electrical outlet. Make sure that any students working with the outlet are NOT touching water. Students who are working with water should NOT be near the electrical outlet. All students must be careful not to touch any metal parts of the heat lamp or bulb once it is plugged in, and up to 30 minutes after it has been unplugged, as it could potentially burn skin. Students should also place the plastic water bottle at least 6 inches away from the bulb of the heat lamp, as placing it any closer to the bulb will cause the plastic to melt. In addition:



- Wear indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activity.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Students will be working with contents that are under pressure, and the thermometer or liquids could spill out if the clay is not secured to the bottle. Immediately wipe up any spilled water on the floor--this is a slip-and-fall hazard.
- Follow procedures set up by your instructor for disposal of materials.
- Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Use caution when working with glassware or plasticware - it can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Direct supervision will be required during all aspects of this activity.
- While Alka-Seltzer is generally safe for use, in case of contact with eyes, rinse immediately with water; after contact with skin, wash immediately; if swallowed, seek medical advice.
  - If you are unable to create a sufficient seal with the given materials, consider placing the thermometer through a 1-hole stopper. Test this beforehand to ensure you do not create a completely airtight seal. An overly tight seal will prevent any carbon dioxide from escaping, which could cause the stopper to pop off in a potentially dangerous fashion.
- DO NOT under any circumstances drill a hole through the bottlecap for the thermometer. This seal will be dangerously tight and may cause the cap to pop off explosively.
- Make sure to securely attach the lamp to a permanent structure or a reign stand.
- **Disposal:** Dispose in accordance with all applicable federal, state, and local regulations. Always contact a permitted waste disposer to ensure compliance. All liquid waste can be disposed of down the drain. Any solid materials that cannot be reused should be disposed of in the garbage bin. However, many items can be reused multiple times, such as water bottles and modeling clay.
- **Storage:** Store Alka-Seltzer in a cool, dry place when not in use. Keep the heat lamp in a cabinet not easily accessible by students when not in use.



## Lesson 8 • Where We Are Going and NOT Going

### Where We Are Going

In this lesson, students build an understanding of the following DCI: element HS-ESS2.D: *Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.*

In this lesson, students investigate the potential impact of large amounts of carbon being released into the atmosphere due to fires burning in carbon sinks that are often the result of human activity.

This lesson builds on students' prior understanding of MS-ESS2.D.1:

*Human activities, such as the release of greenhouse gasses from burning fossil fuels, are significant factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior, and on applying that knowledge wisely in decisions and activities.*

Students continue to develop their use of the science practice *planning and carrying out investigations*. In Lesson 5, students developed directional hypotheses with scaffolds. In this lesson, the scaffolds are removed, and students use this element of the practice more independently.

Students use elements of the crosscutting concept of *cause and effect*. This lesson builds on previous engagement with cause and effect from Lesson 1, when they began to explore how zombie fires lead to changes in the biosphere and atmosphere. In this lesson, they use cause and effect to explain that an increase in concentrations of CO<sub>2</sub> causes an increase in atmospheric temperature.

In this lesson, students will co-construct a definition for *climate change* and *greenhouse gasses*, which they should add to their Personal Glossaries. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

### Where We Are NOT Going

Although this unit builds on previous knowledge of carbon dioxide emissions from burning fossil fuels, it is not the focus of the unit where wildfire and thawing permafrost are the focal sources of atmospheric carbon. Understanding feedback effects from fossil fuel emissions and the geologic time scale of cycling carbon will be further developed in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

This lesson also does not explain the mechanisms of how carbon dioxide works as a greenhouse gas to cause temperature rise, which is explored in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, although students might share these ideas during discussions. Additionally, it does not explain the mechanisms that create increased drought or stronger winds due to higher global temperatures. Climate-related topics are explored in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

Although students may bring these up, the lesson does not address the potential health and ecosystem impacts of wildfire in terms of exposure to smoke, carbon monoxide release, water pollution, and other atmospheric fire outputs. After the investigation, if students are interested in reading about the health effects of greenhouse gasses, direct them to the World Health Organization. (n.d.). *How air pollution is destroying our health*. World Health Organization. <https://www.who.int/news-room/spotlight/how-air-pollution-is-destroying-our-health>

# LEARNING PLAN for LESSON 8

## 1 · NAVIGATE

3 min

MATERIALS: science notebook, *Fires Progress Tracker*

**Facilitate a discussion to support navigation.** Display **slide A**. Ask the class to review their science notebooks and *Fires Progress Tracker* to recall and share what they figured out in the last lesson and what they still want to know using the prompts below as a guide.

| Suggested prompt                                  | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What did we figure out in our last lesson?</i> | <p>Fires are increasing in some places because of increasing drought and rising temperatures.</p> <p>Fires are increasing from human actions like fire suppression in forests, burning for agriculture, and draining peat land.</p> <p>Matter is being reduced by the burning carbon sink, and a lot of energy is being released from the carbon and the burning peat.</p> <p>Carbon moves from the sinks into the air.</p> |
| <i>What do we still want to know?</i>             | <p>Are all carbon sinks more vulnerable to burning and becoming carbon dioxide?</p> <p>What could happen if carbon sinks do burn?</p> <p>Should people care if wildfires add more carbon dioxide to the atmosphere?</p>                                                                                                                                                                                                     |

## 2 · ORIENT TO THE CARBON DIOXIDE-TEMPERATURE INVESTIGATION

7 min

MATERIALS: None

**Motivate investigation of the effect of carbon dioxide on temperature.** Display **slide B**. Say, *I heard you say that burning carbon sinks results in a lot of carbon dioxide in the atmosphere.* Use the prompts below to elicit responses to facilitate a whole-class discussion about the potential impacts this could have.

| Suggested prompt                                                                                                                | Sample student response                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Do you think people should be concerned that wildfires are adding more carbon dioxide to the atmosphere? Why or why not?</i> | <p>It makes the Earth hotter.</p> <p>It is a greenhouse gas.</p> <p>Smoke makes it hard to breathe.</p> <p>It causes pollution.</p>                                                                                                                                                                                                                             |
| <i>How could we figure out the effects of carbon dioxide from fires?</i>                                                        | <p>Burn something and catch the carbon to see what happens/if it makes the air hotter.</p> <p>Pump a glass room full of carbon dioxide and see if it gets warm in the sun.</p> <p>Compare the bottle or glass room with carbon dioxide to one without carbon dioxide to see which is hotter.</p> <p>Look at data related to carbon dioxide and its effects.</p> |

**Review an investigation setup.** Say, *You all have some really great ideas. I have some supplies that will help make it possible for us to investigate this in our classroom.* Provide students with instructions to set up the investigation on *CO2 Investigation Guide*. Display **slide C** and review the investigation setup. Give students a few minutes to read the instructions with their partners. Say, *You will be working with Alka-Seltzer in this investigation. Does anyone have experience with it? What happens when it comes in contact with water?* Display **slide D**. Explain to students that Alka-Seltzer contains carbon and it is released when it reacts in water as carbon dioxide.

### ADDITIONAL GUIDANCE

Alka-Seltzer contains sodium bicarbonate (baking soda) which contains carbon in the form of  $\text{NaHCO}_3$ . It also contains an acidic ingredient, typically citric acid. When dissolved, the the sodium bicarbonate and the acid react forming carbon dioxide gas in the following reaction: Citric acid (aq) + Sodium bicarbonate (aq) → Carbon dioxide + water + Sodium citrate ( $\text{C}_6\text{H}_8\text{O}_7 + 3\text{NaHCO}_3 \rightarrow 3\text{H}_2\text{O} + 3\text{CO}_2 + \text{Na}_3\text{C}_6\text{H}_5\text{O}_7\text{HCO}_3^-$  (aq) +  $\text{H}^+$  (aq) →  $\text{H}_2\text{O}$  (l) +  $\text{CO}_2$  (g)). It is similar to the reaction between baking soda and vinegar that many students will be familiar with. The specifics of the chemical reaction are beyond the scope of this unit and will be addressed in *OpenSciEd High School Chemistry*.

**Map the investigation system.** Ask students to review the materials list and turn and talk to a partner to figure out how the bottle system maps back to an ecosystem. Display **slide E** to show an image of the bottle system and the Cerrado Carbon Sink as an example.

Display **slide F**. Once students have had a moment to discuss, call on volunteers from a few groups to share their ideas. Lead a brief discussion using the prompts below to help them with the mapping. See the chart below as a sample.

| Suggested prompts                                                                                                  | Sample student responses                                 | Follow-up questions                                                                                           |
|--------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| <i>What does the bottle represent?</i>                                                                             | An ecosystem.                                            | <i>Where are the carbon sinks we investigated found?</i>                                                      |
| <i>What does the Alka-Seltzer represent?</i>                                                                       | The carbon sink where the carbon dioxide comes from.     | <i>Think about what we figured out in Lesson 2 and the fire triangle. What role does carbon play in fire?</i> |
| <i>What does the water represent?</i>                                                                              | The water has oxygen/it represents the oxygen fire uses. | <i>What role does oxygen play in a fire?</i>                                                                  |
| <i>When the Alka-Seltzer and water come together, there will be a reaction. What does that reaction represent?</i> | The fire.                                                | <i>What reaction happens in a fire?</i>                                                                       |
| <i>What does the CO<sub>2</sub> in the bottle represent?</i>                                                       | The CO <sub>2</sub> being released into the atmosphere.  | <i>What is released into the atmosphere when a fire burns?</i>                                                |
| <i>What does the heat lamp represent?</i>                                                                          | The Sun.                                                 | <i>Where does the energy come from in an ecosystem?</i>                                                       |

| Ecosystem                               | Bottle System                                                    |
|-----------------------------------------|------------------------------------------------------------------|
| Ecosystem                               | Bottle                                                           |
| Fuel/carbon sink                        | Alka-Seltzer tablet                                              |
| Has the oxygen in it                    | Water                                                            |
| Fire reaction                           | Water + Alka-Seltzer react                                       |
| Increased CO <sub>2</sub> in atmosphere | Increased CO <sub>2</sub> in bottle (from Alka-Seltzer reaction) |
| Sun/Heat                                | Heat Lamp                                                        |



**Investigate the effect of increasing carbon dioxide on temperature.** Display slide G. Instruct students to go back to *CO<sub>2</sub> Investigation Guide* to finish reading the setup instructions. They should mark up the instructions by underlining important information and adding question marks to note anything that is confusing to them. Then ask students to share any question marks they added to clarify the procedure.

### 3 · DEVELOP DIRECTIONAL HYPOTHESES

5 min

MATERIALS: CO2 Temperature Investigation

 **Develop directional hypotheses.** Say, *In our investigation, we are looking at the relationship between two different variables, carbon dioxide and temperature. Display slide H. Lead a brief discussion of what students figured out in Lesson 5 about directional hypotheses. Distribute CO2 Temperature Investigation. Say, Take a moment individually to write a directional hypothesis in CO2 Temperature Investigation. \* You will also need to identify which variable is the independent and which is the dependent variable in the “Before the Investigation” part of your handout.*

#### ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:**

- A **directional relationship** between **increasing carbon dioxide concentration** and **increasing temperature**. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)
- Identifying that the **carbon dioxide concentration** is the **independent variable** and the **temperature** is the **dependent variable** in the bottle system. (SEP: 3.5; DCI: ESS2.D.3)

**What to do:** Circulate and review *CO2 Temperature Investigation* from each student with your roster and mark whether students correctly identify the variables and the direction of the relationship. Use prompts such as: *Which variable are we manipulating in the investigation? or Which variable responds to the changes that we made?* If students do not choose the correct direction of the relationship, ask them to explain the relationship in pictures or words with prompts such as, *We know that carbon dioxide is released in the fire. What is that doing to the concentration of carbon dioxide? How could that change in carbon dioxide affect the temperature?* For students who need additional support, refer to the scaffolds used in Lesson 5: *Hypothesis Development*.

**Building toward 8.A.1** Make a directional hypothesis to specify what happens to **temperature (effect)** when **carbon dioxide concentrations in the atmosphere increase due to burning (cause)**. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)

### 4 · CONDUCT CARBON DIOXIDE-TEMPERATURE INVESTIGATION

20 min

MATERIALS: Carbon Dioxide-Temperature Investigation, safety goggles, non-latex apron, nitrile gloves, Community Agreements

**Review Community Agreements that will support the investigation.** Say, *Before we begin our investigation, let's check in on our Community Agreements. Which agreement do you think would help us be most successful in our investigation today?* Display **slide I** and listen to students' ideas. Review the co-developed Community Agreements with the class if students need additional support.\*



**Review safety considerations for the investigation.** Display **slide J** and **K**.

#### \* ATTENDING TO EQUITY

**Universal Design for Learning:** Using the Community Agreements to continually cultivate an equitable learning community that promotes trusting and caring relationships that foster student engagement is essential. The agreements should remind students to value the diversity of classroom community members and equity in the sensemaking work they will do together this school year. It is critical that the agreements support safe and fair participation and interrupt cultural norms or stereotypes that could make science experiences feel uncomfortable to students.

## SAFETY PRECAUTIONS



Emphasize that it is necessary to wear goggles because the contents of the bottle will be under pressure and could come off unexpectedly. The heat lamps will get extremely hot, so students should not touch them. The bottles should be about 12 inches from the lamps so the clay does not melt. If this is not possible, rotate the bottles every four minutes. If Alka-Seltzer tabs are too large, break them to fit in the bottle. Also, to collect the most accurate data, encourage students to get the caps onto the bottles as quickly and safely as possible after adding the Alka-Seltzer so less gas escapes. Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.

Students will be working with a heat lamp plugged into an electrical outlet. Make sure that any students working with the outlet are NOT touching water. Students who are working with water should NOT be near the electrical outlet. All students must be careful not to touch any metal parts of the heat lamp or bulb once it is plugged in and up to 30 minutes after it has been unplugged, as it could potentially burn skin. Students should also place the plastic water bottle at least 6 inches away from the bulb of the heat lamp, as placing it any closer to the bulb will cause the plastic to melt.

In addition, use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.

Spills should be cleaned up right away. See materials preparation for additional safety guidance.

**Carry out the investigation.** Display **slide L**. Divide students into groups of 4 to carry out the investigation. Direct students to assign roles in their groups to help manage the materials and data collection. Assign groups to share a heat lamp as needed.

## ADDITIONAL GUIDANCE

Although this can be a challenging investigation, it is the best way for students to see the relationship between CO<sub>2</sub> and temperature.

Using your particular equipment, you may have to test the investigation in advance to determine the best distance for the lamps and bottles in your setup compared to the recommended distance and images included in the lesson materials. Once you have figured out your setup, completing the investigation will take about 20 minutes. More replications are better if the budget permits.

In testing this investigation, developers used Aquafina plastic bottles, Crayola clay, and 250W bulbs. Other materials may yield different results.

## 5 · MAKE SENSE OF THE CARBON-DIOXIDE TEMPERATURE INVESTIGATION

7 min

MATERIALS: *CO2 Temperature Investigation*

**Make sense of data in small groups.** Display slide M. After groups are done collecting their data, have students answer the Making Sense questions in their small groups. Pause to discuss the Making Sense questions on *CO2 Temperature Investigation* as a class. Say, *When scientists see that their data aligns with their hypothesis, they support it. If it does not align, they say that they refute their hypothesis. \**

### ADDITIONAL GUIDANCE

If students need additional support in creating a graph, guide them through a discussion to help them properly label axes and choose a reasonable scale for time (x-axis) and temperature (y-axis). Students may need prompting to consider putting the results of both bottles on the same graph or to do the math to decide on the best scale.



**Collect *CO2 Temperature Investigation*.** Ask students to submit *CO2 Temperature Investigation* at the end of the class period to assess individual student progress from day 1. Use *CO2 Investigation Responses* to help you provide feedback before day 2.

### ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:**

- A **directional relationship** between **increasing carbon dioxide concentration** and **increasing temperature**. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)
- Identifying that the **carbon dioxide concentration** is the **independent variable** and the **temperature** is the **dependent variable** in the bottle system. (SEP: 3.5; DCI: ESS2.D.3)
- While keeping everything else constant, the **temperature increased** faster and leveled off at a higher temperature **in the bottle with the higher concentration of carbon dioxide** than the control bottle to prove that **carbon dioxide causes temperature** to rise (effect). (DCI: ESS2.D.3; CCC: 2.2)

**What to do:** Collect *CO2 Temperature Investigation* from each student. Use *CO2 Investigation Responses* to provide feedback to students before day 2.

**Building toward 8.A.2** Make a directional hypothesis to specify what happens to **temperature (effect)** when **carbon dioxide concentrations in the atmosphere increase due to burning (cause)**. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)



## 6 · NAVIGATE

3 min

MATERIALS: None

**Turn and Talk.** Display **slide N**. Tell students to imagine that they are texting a friend and share one sentence to explain their choice of the following questions:

- What progress did we make in figuring out the effects of carbon dioxide in the atmosphere from fires in ecosystems?
- Now that we have figured this out at the scale of an ecosystem, what data do we need to understand this at the scale of the Earth?

### End of day 1

## 7 · NAVIGATE

5 min

MATERIALS: *CO2 Temperature Investigation*, science notebook

**Navigate into today's work.** Display **slide O**. Hand back *CO2 Temperature Investigation* to students with feedback. Give students 5 minutes to make any revisions to *CO2 Temperature Investigation* based on your feedback.

## 8 · BUILDING UNDERSTANDINGS DISCUSSION

10 min

MATERIALS: science notebook, *CO2 Temperature Investigation*

**Facilitate a Building Understandings Discussion.** Display **slide P**. Bring the class together in a Scientists Circle with *CO2 Temperature Investigation*. Explain that you will facilitate a Building Understandings Discussion about the evidence students collected about the relationship between carbon dioxide and temperature. Remind them that the teacher's role in this type of discussion is to ask students to justify their choices, prompt them for evidence, and ask other groups to either agree or propose alternatives to what is presented. Follow-up questions should not surprise or deter students because they are figuring out different ideas. Ask a few groups to share their ideas and come to an agreement on the interpretation of the investigation results. \*

### \* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful kind of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and claims and to push them to support their claims with evidence. Students can disagree with each other and the class does not need to reach consensus on all ideas shared. Areas of disagreement can motivate future investigations. Helpful prompts during these kind of discussions include:

- What can we conclude?
- How did you arrive at that conclusion?
- What's your evidence?
- Does any group have evidence to support Group A's claim?
- What data do we have that challenges Group B's claim?

#### Suggested prompt

*What was the independent and dependent variable?*

*How did changing the independent variable cause changes to the dependent variable?*

*Review your hypothesis. Is there a directional relationship between these variables? Explain.*

#### Sample student response

The independent variable was the carbon dioxide, and the dependent variable was the temperature.

When we added carbon dioxide to the bottle, the air temperature increased more.

Adding carbon dioxide to the bottle system caused a temperature increase in the air.

Yes, as carbon dioxide increases, temperature also increases.

| Suggested prompt                                                                                                                                                         | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>How does this relate to fires in ecosystems with carbon sinks that we investigated, such as the Great Dismal Swamp, Australia, Cerrado, California, and Cambodia?</i> | Those systems are putting carbon dioxide into the air through fires, which will make the atmosphere hotter.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>KEY IDEAS</b>                                                                                                                                                         | <p><b>Purpose of the discussion:</b> To make sense of the relationship between carbon dioxide and temperature in the bottle system and relate it to fires in ecosystems.</p> <p><b>Listen for these ideas:</b></p> <ul style="list-style-type: none"> <li>Carbon dioxide is the independent variable, and temperature is the dependent variable.</li> <li>The temperature in the system with added carbon dioxide increased faster than in the system without carbon dioxide and leveled out at a higher temperature.</li> <li>Evidence that the system with carbon dioxide was X degrees warmer than the system without carbon dioxide.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>ADDITIONAL GUIDANCE</b>                                                                                                                                               | <p>At some point in the lesson, students are likely to bring up the idea that carbon dioxide is a greenhouse gas. They may already have experienced learning about greenhouse gasses and related ideas in middle school. <i>Human activities, such as the release of greenhouse gasses from burning fossil fuels, are significant factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities (MS-ESS3.D).</i> While the mechanism needed to fully explain greenhouse gasses will be explored further in OpenSciEd Chemistry, encourage them to add a definition to their Personal Glossaries to explain their current understanding about gasses that can trap heat in the atmosphere.</p> |

## 9 • TURN AND TALK ABOUT GLOBAL TEMPERATURE AND CO<sub>2</sub>

5 min

**MATERIALS:** None

**Turn and talk about the global system.** Review the prompts on **slide Q** and ask students to turn and talk about the prompts on the slide. Then call on a few pairs to share their ideas. Listen for students to share ideas about how ecosystems are connected through Earth's atmosphere and how changes in one system affect all of the other systems.

## 10 • REVISE DIRECTIONAL HYPOTHESES FOR THE GLOBAL SYSTEM

5 min

**MATERIALS:** CO<sub>2</sub> Temperature Investigation, science notebook



**Revise directional hypotheses.** Display **slide R**. While still in their pairs, ask students to review their directional hypotheses on CO<sub>2</sub> Temperature Investigation. Then ask them to explain the relationship between temperature and atmospheric carbon dioxide concentrations on the global scale by writing a new directional hypothesis in their science notebooks. Call on a few pairs to share their hypotheses. Lead a brief discussion using the prompts below.

| Suggested prompt                                              | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| What was your directional hypothesis?                         | As carbon dioxide concentrations increase globally due to fires in many systems, the global temperature will increase in Earth's atmosphere.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| How can we find evidence to support or refute our hypotheses? | <p>We can look at data that scientists have collected.</p> <p>We can look at carbon dioxide levels in the atmosphere and compare it to temperature data that has been collected over many years.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>ASSESSMENT OPPORTUNITY</b>                                 | <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>A <b>directional relationship</b> between <b>increasing carbon dioxide concentration</b> from fire in many ecosystems and <b>increasing global temperature</b>. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)</li> </ul> <p><b>What to do:</b> Circulate around the room and review the hypotheses students record in their science notebooks. Focus on supporting students who had difficulty specifying the relationships between variables on day 1.</p> <p><b>Building toward 8.A.3</b> Make a directional hypothesis to specify what happens to <b>temperature (effect)</b> when <b>carbon dioxide concentrations in the atmosphere increase due to burning (cause)</b>. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)</p> |

## 11 · ANALYZE GLOBAL CARBON DIOXIDE DATA

15 min

**MATERIALS:** *Global Temperature/CO2 Data*

**Introduce global data.** Say, *I found some global data that might answer some of our questions.* Distribute *Global Temperature/CO2 Data*. Display slide S, showing the same graph of global carbon dioxide and temperature over time.

### ADDITIONAL GUIDANCE

Support students as they make sense of the graph. Students may not be familiar with graphs that have two vertical axes. In this case time (years) is on the horizontal axes and both global temperature and carbon dioxide concentrations are on the vertical axes. Use prompts such as: *How does this graph compare to the graphs we made following our investigation? What other ways are there to look at this data? How does looking at all three variables at the same time help us make sense of the data?*

**Turn and talk about global data.** Display slide T and ask students to turn and talk about the graph using the questions on the slide as a guide. Note: The increasing carbon dioxide levels shown in these graphs come from a number of sources, including wildfires. This lesson focuses on burning carbon sinks as a source, but students may bring up other sources.

**Whole-class discussion about global data.** Bring the class together to share their thoughts. Facilitate a whole-class discussion about what they figured out from the graph.

| Suggested prompt                                                                                                                                                                                                                                                                                                                                             | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><i>What evidence does this graph give us to answer our questions about the larger-scale effects of adding more carbon dioxide to the atmosphere?</i></p> <p><i>How does it relate to the data we collected in our investigation in the last class?</i></p> <p><i>What other systems could be affected by increased temperature in the atmosphere?</i></p> | <p>The graph shows global temperature and atmospheric carbon dioxide.</p> <p>Both carbon dioxide on Earth and temperature rise together over time.</p> <p>It shows a correlation between rising temperature and more carbon dioxide.</p> <p>Both the bottle system investigation and this graph show temperature rises as carbon dioxide levels rise.</p> <p>In the investigation, we only changed carbon dioxide amounts, so we could say that carbon dioxide caused the temperature to rise, but for the global data we do not know the cause. We can only say the rise is correlated.</p> <p>The bottle system was on a smaller scale than the global data.</p> <p>Oceans and other bodies of water could get warmer.</p> <p>Some animals and plants may not be able to survive the increased temperatures.</p> <p>There are more storms that are worse.</p> |
| <b>ADDITIONAL GUIDANCE</b>                                                                                                                                                                                                                                                                                                                                   | <p>Students may ask about the connection between rising temperature and drought. If students experienced OpenSciEd Middle School <i>Storms Unit</i>, they may recall investigating this relationship. Discuss how evaporation happens more quickly with rising temperatures, drying out soil and vegetation. This makes periods with lower precipitation even drier than they would be if the temperature were cooler. This is a simplified explanation of more complex weather and climate systems, which will be further explored in <i>Fuels Unit</i> and <i>Polar Ice Unit</i>.</p> <p>If questions come up about other human sources of carbon dioxide, like fossil fuel emissions, encourage students to record those ideas so they can use them in future lessons.</p>                                                                                   |
| <b>ALTERNATE ACTIVITY</b>                                                                                                                                                                                                                                                                                                                                    | <p><b>Extension opportunity:</b> If students want to better understand the relationship between photosynthesis and global atmospheric carbon dioxide levels, ask them to look at the patterns found in the data from the Mauna Loa Observatory. This shows that plants can cause seasonal fluctuations on a large scale. Play the animation at <a href="https://gml.noaa.gov/ccgg/trends/history.html">https://gml.noaa.gov/ccgg/trends/history.html</a> (from the beginning until 1:36) or look at the static image of the data at <a href="https://gml.noaa.gov/ccgg/trends/">https://gml.noaa.gov/ccgg/trends/</a>.</p>                                                                                                                                                                                                                                      |

**Update Personal Glossaries.** Display **slide U**. It is likely in this discussion, that students will have co-constructed what we mean when we say climate change. If so, add to Personal Glossaries now; if not, you can add later in the lesson. Say, *It sounds like we may expect this trend of temperatures increasing to continue in the future. When we see long-term temperature or other trends changing for a certain place or system, we have a name for this trend. It is called climate change.*

## ADDITIONAL GUIDANCE

Note that students may already have experienced learning about climate change from middle school. *Human activities, such as the release of greenhouse gasses from burning fossil fuels, are significant factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior, and on applying that knowledge wisely in decisions and activities (MS-ESS3.D).*

## 12 · NAVIGATE: UPDATE PROGRESS TRACKERS

10 min

**MATERIALS:** science notebook, *Fires Progress Tracker*

**Update Progress Trackers.** If time permits, display **slide V** and ask students to complete a new row in *Fires Progress Tracker*. One possible representation of a completed Progress Tracker is shown below.

|                                                                                                | What we figured out (WWFO)                                        | How does WWFO help us make progress on our Driving Question about zombie fires?                                                | How does WWFO connect to me or my community or have a larger-scale impact?                                                                                    | What questions do I have now?                                                                                                                                                                                                                                                                            |
|------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Lesson 8:</b><br>Why should we be concerned that carbon sinks around the world are burning? | -Increased carbon dioxide in the air causes temperatures to rise. | We see that there is a directional hypothesis that if you increase carbon dioxide, then the temperature will increase as well. | Now that we have done this investigation, it is even scarier when I watch the news and they talk about carbon dioxide levels in the air and the rising ocean. | -Does the increase in carbon dioxide increase the temperature on Earth like it does in the bottles?<br><br>-How can we protect carbon sinks from burning?<br><br>-Can we create more carbon sinks?<br><br>-People do things that make carbon sinks vulnerable to burning. What can they do to stop them? |

### ALTERNATE ACTIVITY

**Extension activity:** By this time in the unit, students may be inquiring about how they can make different choices that could reduce the amount of carbon that they produce with their lifestyle (carbon footprint). It is important to elevate these concerns and questions and inspire student agency.

Share the U.S. Environmental Protection Agency's Energy Star Carbon Footprint Survey [https://www.energystar.gov/ia/products/globalwarming/downloads/GoGreen\\_Activities%20508\\_compliant\\_small.pdf](https://www.energystar.gov/ia/products/globalwarming/downloads/GoGreen_Activities%20508_compliant_small.pdf) and calculator <https://www.footprintcalculator.org/home/en> to help students collect baseline data to measure the impact of their decision-making on the flow of carbon in their area.

## Additional Lesson 8 Teacher Guidance

### SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

**CCSS.MATH.CONTENT.HSN.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

Students make graphs to represent data collected during their investigation. They choose the proper units, scale, and axes.



# LESSON 9: What are the global effects of increased carbon dioxide from fires?

## PREVIOUS LESSON

We investigated the effect of increased carbon dioxide on temperature with a bottle system designed to simulate fires in ecosystems. We developed directional hypotheses and collected evidence to support our hypotheses. We revised our hypotheses to explain the relationship between atmospheric carbon dioxide and temperature at the global scale and investigated data collected by scientists. We wondered how the relationship between carbon dioxide and temperature affects other systems.

## THIS LESSON

INVESTIGATION, PUTTING PIECES TOGETHER

2 days



### Atmosphere

| Dice roll | What happens?                                                                                                                                                                                                                                                   | Where to next? |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|
| 1 - 2 - 3 | You remain in the atmosphere as a molecule of carbon dioxide, CO <sub>2</sub> (matter). Energy remains in the same arrangement of atoms. Record this action and roll again.                                                                                     | Atmosphere     |
| 4         | You enter the ocean as carbon dioxide, CO <sub>2</sub> , and are dissolved in the water (matter). Energy flows to a new system in the same arrangement of atoms.                                                                                                | Ocean          |
| 5 - 6     | You are taken in by a producer as carbon dioxide, CO <sub>2</sub> . The producer uses energy from sunlight and water to rearrange you into molecules used to build biomass (matter) of the producer. Energy flows to a new system AND the atoms are rearranged. | Producers      |

We use a quantitative model to simulate how carbon and energy flow through Earth's systems. We develop a GottaHavelt Checklist and consensus model to explain the implications of rising carbon dioxide levels and temperatures on Earth's systems. We decide to investigate ways to manage carbon sinks to reduce feedback effects from climate change in relation to fires.

## NEXT LESSON

We will investigate four case studies of successful fire management. We will figure out how prescribed burning, cultural burning, restoring grazer populations, and replanting forests help manage the amount of available carbon and energy that could burn in wildfires. We will develop a mathematical representation to explain how these techniques could alter the flow of energy and matter in these ecosystems.

## BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



## WHAT STUDENTS WILL DO

**9.A** Develop and use a complex, quantitative model that allows for manipulation to explain the flow of carbon (matter) and energy within and between the systems of the hydrosphere, atmosphere, geosphere, and biosphere through chemical, physical, geological, and biological processes. (SEP: 2.5; DCI: LS2.B.3; CCC: 4.3)

**9.B** Develop a model to explain how energy from the Sun and wildfires drives the cycling of carbon, leading to a rise in carbon dioxide concentrations and atmospheric temperatures. (SEP: 2.3; DCI: LS2.B.3, ESS2.D.3; CCC: 5.4)

## WHAT STUDENTS WILL FIGURE OUT

- Earth is made up of many systems that energy and matter flow through.
- Our qualitative model explains that the energy and matter in
- A (positive) feedback effect is created as increased carbon dioxide causes increased temperature and increased temperature causes more drought, which leads to more wildfires that release additional carbon dioxide into the atmosphere, which makes more carbon available in other spheres.



## Lesson 9 • Learning Plan Snapshot

| Part                | Duration |                                                                                     | Summary                                                                                                                                                                                                                                              | Slide | Materials                                                                                                                                                                                                                                                                           |
|---------------------|----------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                   | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Review questions and ideas for investigation from the last lesson.                                                                                                                                                                | A     |                                                                                                                                                                                                                                                                                     |
| 2                   | 10 min   |                                                                                     | <b>INITIAL IDEAS ABOUT ENERGY AND MATTER IN OTHER EARTH SYSTEMS</b><br>Motivate identifying the components and interactions for the Earth Systems Model by reviewing what students know from earlier grades.                                         | B-E   | whiteboard and dry erase markers or chart paper and chart paper markers, chart paper, chart paper markers                                                                                                                                                                           |
| 3                   | 20 min   |    | <b>USE A QUANTITATIVE MODEL TO SIMULATE THE FLOW OF CARBON AND ENERGY THROUGH EARTH'S SYSTEMS</b><br>Simulate the flow of carbon (matter) and energy through Earth's systems and use a quantitative model.                                           | F-J   | Carbon/Energy Quantitative Model                                                                                                                                                                                                                                                    |
| 4                   | 10 min   |                                                                                     | <b>FACILITATE A BUILDING UNDERSTANDINGS DISCUSSION ABOUT THE CARBON ATOM JOURNEY</b><br>Move to a Scientists Circle. Lead a Building Understandings Discussion to make sense of the relationships between the matter and energy flow of each system. | K     | <i>Carbon/Energy Quantitative Model</i>                                                                                                                                                                                                                                             |
| 5                   | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Motivate next steps.                                                                                                                                                                                                              | L     |                                                                                                                                                                                                                                                                                     |
| <i>End of day 1</i> |          |                                                                                     |                                                                                                                                                                                                                                                      |       |                                                                                                                                                                                                                                                                                     |
| 6                   | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Read and review feedback on <i>Carbon/Energy Quantitative Model</i> .                                                                                                                                                             | M     |                                                                                                                                                                                                                                                                                     |
| 7                   | 10 min   |                                                                                     | <b>BRAINSTORM COMPONENTS FOR GOTTA-HAVE-IT CHECKLIST</b><br>Build a checklist of components, interactions, and mechanisms for building a model of global carbon cycling related to wildfires.                                                        | N     | <i>Carbon/Energy Quantitative Model</i> , chart paper, chart paper markers                                                                                                                                                                                                          |
| 8                   | 10 min   |  | <b>COMPARE AND REVISE GOTTA-HAVE-IT CHECKLISTS</b><br>Work in groups to revise components, interactions, and mechanisms to checklists after peer review.                                                                                             | O-P   | 3x3 sticky notes                                                                                                                                                                                                                                                                    |
| 9                   | 15 min   |  | <b>DEVELOP A CLASS CONSENSUS MODEL</b><br>Facilitate a class discussion to develop a model to explain <i>How do rising carbon dioxide levels and temperatures from burning carbon sinks affect other Earth systems?</i>                              | Q-R   | chart paper, chart paper markers                                                                                                                                                                                                                                                    |
| 10                  | 10 min   |  | <b>NAVIGATE</b><br>Share questions and ideas for reversing feedback effects. Facilitate completion of an Electronic Exit Ticket.                                                                                                                     | S-T   | internet-connected device, <a href="https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8JH3RBgVLKqLv9h48WoEaL7TA6Q/copy">https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8JH3RBgVLKqLv9h48WoEaL7TA6Q/copy</a> , Related Phenomena poster, DQB, 3x3 sticky notes, chart paper markers |

| Part | Duration |  | Summary | Slide | Materials |
|------|----------|--|---------|-------|-----------|
|------|----------|--|---------|-------|-----------|

*End of day 2*

## Lesson 9 • Materials List

|                                            | per student                                                                                                                                                                                                                                                                                                                                                                                                                                        | per group                                                                                                                                                                                             | per class                                                                                                                                                                                                                                                                 |
|--------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Carbon/Energy Quantitative Model materials | <ul style="list-style-type: none"> <li>1 die</li> <li><i>Carbon/Energy Quantitative Model</i></li> <li>internet-connected device</li> <li><a href="https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN_easjOmXjXfUkCpMVA/edit?usp=sharing">https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN_easjOmXjXfUkCpMVA/edit?usp=sharing</a></li> <li><i>Carbon/Energy Data from Quantitative Model</i> (optional)</li> </ul> |                                                                                                                                                                                                       | <ul style="list-style-type: none"> <li><a href="https://docs.google.com/presentation/d/1gqla_dNfc4SEq66n888e2wOahm7cUS5GNLLreQon4qU/edit?usp=sharing">https://docs.google.com/presentation/d/1gqla_dNfc4SEq66n888e2wOahm7cUS5GNLLreQon4qU/edit?usp=sharing</a></li> </ul> |
| Lesson materials                           | <ul style="list-style-type: none"> <li>science notebook</li> <li><i>Carbon/Energy Quantitative Model</i></li> <li>internet-connected device</li> <li><a href="https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8JH3RBgVLKqLv9h48WoEaL7TA6Q/copy">https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8JH3RBgVLKqLv9h48WoEaL7TA6Q/copy</a></li> </ul>                                                                                                  | <ul style="list-style-type: none"> <li>whiteboard and dry erase markers or chart paper and chart paper markers</li> <li>chart paper</li> <li>chart paper markers</li> <li>3x3 sticky notes</li> </ul> | <ul style="list-style-type: none"> <li>chart paper</li> <li>chart paper markers</li> <li>Related Phenomena poster</li> <li>DQB</li> <li>3x3 sticky notes</li> </ul>                                                                                                       |

### Materials preparation (20 minutes)

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

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

Be sure your DQB, Community Agreements, and related phenomena are visible for reference during this lesson.

#### Day 1:

- Create groups of 4-6 students to brainstorm about Earth systems.
- Have whiteboard and whiteboard markers available for each group.

#### Day 2:

- Gather chart paper and chart paper markers for developing the consensus model.
- Create groups of 4-6 students to build the Gotta-Have-It Checklists.
- Obtain an internet-connected device for each student to complete <https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8JH3RBgVLKqLv9h48WoEaL7TA6Q/copy>, or print a version for each student.

#### Carbon/Energy Quantitative Model

- Group size:** Individual students. If needed, pair students to support their learning needs.
- Setup:**
  - Print the Carbon/Energy Quantitative Model Cards [https://docs.google.com/presentation/d/1gqla\\_dNfc4SEq66n888e2wOahm7cUS5GNLLreQon4qU/edit?usp=sharing](https://docs.google.com/presentation/d/1gqla_dNfc4SEq66n888e2wOahm7cUS5GNLLreQon4qU/edit?usp=sharing) before class.
  - Note: You will want multiple locations for the atmosphere and the biosphere to reduce crowding, as students spend the most time in these systems.
  - Establish 7 stations in your classroom, one for each system.
  - Place the card for each system at a station.
  - Gather one die per student (or student pair depending on your grouping).
  - Obtain an internet-connected device for each student or pair or print *Carbon/Energy Data from Quantitative Model*.
- Notes for during the lab:**

- If you do not have access to computers/devices or choose not to use them, modify *Carbon/Energy Quantitative Model* with the tables from the total [https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN\\_easjOmXjXfUkCpMVA/edit?usp=sharing](https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN_easjOmXjXfUkCpMVA/edit?usp=sharing) to create a printed version.
- **Safety:** If students are moving around with computers, make sure to have them follow whatever school safety procedures are keeping technology safe.

This modeling activity was adapted from the following resources:

- <https://carbontime.create4stem.msu.edu/ecosystems/activity-3.2>
- <https://www.rainforest-alliance.org/resource-item/climate-curricula/>

## Lesson 9 • Where We Are Going and NOT Going

### Where We Are Going

In this lesson, students use and develop models to explain how energy and matter flow through Earth's systems with emphasis on the carbon cycle.

Students should already know several concepts built in earlier NGSS grade bands related to the movement of material across Earth's systems and carbon dioxide emissions from burning fossil fuels as a cause of climate change, which includes higher temperatures and more frequent droughts.

- **MS ESS2.D:** Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.
- **MS ESS3.D:** Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior, and on applying that knowledge wisely in decisions and activities.
- **MS LS2.B: Cycle of Matter and Energy Transfer in Ecosystems:** Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.

In this lesson, students build toward a complete understanding of the following HS DCI(s):

- ESS2.D.3: Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- LS2.B.3: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

Students continue to develop and use the science practice: *Developing and Using Models* as well as the focal crosscutting concepts of *Energy and Matter* and *Systems and System Models*. This lesson builds toward a consensus model that combines an understanding of photosynthesis and cellular respiration, built in Lesson 6, with the ecosystem models of carbon and energy cycling created in Lesson 7. It adds global-scale impacts of burning carbon sinks. Connecting the global scale to previous models introduces the dynamic feedback effects in this complex system. This model is revised over multiple days over the course of the unit, which allows students to spend time developing and using their models. This model also involves students explaining the matter and energy flow within and between Earth's systems as a whole but also within and between individual subsystems—the hydrosphere, atmosphere, geosphere, and biosphere. The quantitative addition in this model will inform the proportional model of energy moving through a food web students will create in Lesson 10. Students should already know from the middle school CCC *Systems and System Models* elements that:

- Systems may interact with other systems; they may have subsystems and be a part of larger complex systems.
- Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems.

Students co-construct definitions for *carbon cycle* and *feedback effects*, which they should add to their Personal Glossaries. Students will encounter the words *geosphere* and *hydrosphere* from earlier grade bands of the NGSS. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

### Where We Are NOT Going

Although this unit builds on previous knowledge of carbon dioxide emissions from burning fossil fuels, wildfire and thawing permafrost are not primarily considered sources of atmospheric carbon. Feedback effects from fossil fuel emissions and the geologic time scale of cycling carbon will be further developed in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, respectively.

Although students may bring these up, the lesson does not address the potential health and ecosystem impacts of wildfire related to smoke, carbon monoxide release, water pollution, and other outputs of fire.

If students want to better understand the relationship between photosynthesis and global atmospheric carbon dioxide levels, ask them to look at the patterns found in the data from the Mauna Loa Observatory. This shows that plants can cause seasonal fluctuations on a large scale. Play the animation <https://gml.noaa.gov/ccgg/trends/history.html> (from the beginning until 1:36) or look at <https://gml.noaa.gov/ccgg/trends/> for the static image of data.

# LEARNING PLAN for LESSON 9

## 1 · NAVIGATE

5 min

MATERIALS: science notebook

Ask students to recall what they figured out from the Carbon Dioxide-Temperature Investigation and *Global Temperature/CO2 Data* in Lesson 8. Use the prompts on slide A as a guide.

| Suggested prompt                                                                                                             | Sample student response                                                                                                                                                                                                                                                                                                                                 |
|------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What did we figure out from our Carbon Dioxide-Temperature Investigation in Lesson 8 and Global Temperature/CO2 Data?</i> | We represented an ecosystem with a bottle and light and added carbon dioxide (using Alka Seltzer).<br><br>When a light shines on the bottle with added carbon dioxide, the temperature bottle system increased more than one without added carbon dioxide.<br><br>Both global carbon dioxide and temperature rise in the atmosphere together over time. |
| <i>What additional questions did we have about the effects of increases in carbon dioxide and temperature?</i>               | We wanted to know how the increase in carbon dioxide from burning carbon sinks and temperature in the atmosphere affects other systems on Earth.                                                                                                                                                                                                        |

## 2 · INITIAL IDEAS ABOUT ENERGY AND MATTER IN OTHER EARTH SYSTEMS

10 min

MATERIALS: whiteboard and dry erase markers or chart paper and chart paper markers, chart paper, chart paper markers

Facilitate an Initial Ideas Discussion about Earth Systems. Display slide B. Use the prompts below as a guide.\*

| Suggested prompts                          | Sample student responses                                                                                 | Follow-up questions                                                                                                   |
|--------------------------------------------|----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| <i>What other Earth systems are there?</i> | The oceans.<br><br>All the plants and animals.<br><br>Weather.<br><br>Rocks and other geologic features. | <i>We named the atmosphere. What other systems are there in Earth's larger system?</i><br><br><i>Display slide C.</i> |

### \* STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

For each discussion type, the teacher takes on a slightly different stance in facilitation. Be explicit with students about your role in this discussion. Your role is to capture all student ideas (whether “right” or “wrong”), build excitement, and encourage as many students to participate as possible. Meanwhile, emphasize to students that they should share as many ideas as possible. Make space for all students to share their ideas (possibly connected to experiences they have had outside school as well). Encourage student-to-student talk with a focus on raising questions, clarifying, or adding on to what someone has said, rather than debating

| Suggested prompts                                                                                                                                                                                                                                                                                                                                                                                                                                        | Sample student responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Follow-up questions                                                                                                                                                                                                               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><i>What else do we know about these systems from our last unit about the Serengeti or from our experiences that can help us figure out how fire will affect them?</i></p> <p><i>How might increasing carbon dioxide and temperature in the atmosphere affect Earth's other systems?</i></p> <p><i>What new information would we need to investigate the implications of rising carbon dioxide levels and temperatures on other Earth systems?</i></p> | <p>Water, ice, wind, living organisms, and gravity break rocks, soils, and sediments into smaller particles and move them around. So fire might do that as well?</p> <p>The wildebeest interacted with the grass, which interacted with the rain.</p> <p>The oceans might get warmer, which might affect other things that live there.</p> <p>Plants and animals (and other organisms) might be affected because they can or cannot deal with the added temperature and carbon dioxide .</p> <p>We would need data on what happens to the matter and energy in each of Earth's systems.</p> <p>We would need to simulate how the systems are connected through matter and energy changes.</p> | <p><i>What phenomenon have you investigated, experienced, heard about that happens in these other systems?</i></p> <p><i>What phenomenon did we investigate in our last unit? Which of Earth's systems did we prioritize?</i></p> |

or arguing. Students might also use head nods or hand signals to show that they had a similar idea to a classmate's. Keep a class record of these initial ideas (such as on chart paper, a slide, or a shared digital document) for students to refer to later in the lesson—for example, when creating questions for the DQB. More guidance on the Initial Ideas Discussion may be found in the *OpenSciEd Teacher Handbook: High School Science*.

## KEY IDEAS

**Purpose of this discussion:** Provide students a supportive opportunity to voice partial understandings about Earth systems (spheres) developed in prior grade bands.

**Listen for ideas that include the following components:**

- Geosphere: solid and molten rock, soil, and sediments.
- Hydrosphere: ice, water vapor, and liquid water in the atmosphere, ocean, lakes, streams, soils, and groundwater.
- Biosphere: living organisms of any type; life can be found in many parts of the geosphere, hydrosphere, and atmosphere.
- Atmosphere: the envelope of gas surrounding the planet.

## ADDITIONAL GUIDANCE

In regard to **ESS2.A: Earth Materials and Systems**, the NRC Framework explains that Earth is a complex system of interacting subsystems: the geosphere, hydrosphere, atmosphere, and biosphere. The geosphere includes a hot and mostly metallic inner core; a mantle of hot, soft, solid rock; and a crust of rock, soil, and sediments. The atmosphere is the envelope of gas surrounding the planet. The hydrosphere is the ice, water vapor, and liquid water in the atmosphere, ocean, lakes, streams, soils, and groundwater. The presence of living organisms of any type defines the biosphere; life can be found in many parts of the geosphere, hydrosphere, and atmosphere. Humans are of course part of the biosphere, and human activities have important impacts on all of Earth's systems.

The NGSS asks students to work with the following ideas in the 3-5 grade band.

- Earth's major systems are the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans).
- These systems interact in multiple ways to affect Earth's surface materials and processes.
- The ocean supports a variety of ecosystems and organisms, shapes landforms, and influences climate. Winds and clouds in the atmosphere interact with the landforms to determine patterns of weather.

The middle school grade band develops the following ideas:

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems.
- This energy is derived from the Sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.
- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.

**Turn and talk about modeling to generate evidence.** Say, *In the Serengeti Unit, we did a lot of work to generate evidence about interactions using the lens of stability and change of populations. How can we use models now to generate evidence about interactions using the lens of matter and energy in Earth's systems?* Display **slide D** and ask students to turn and talk about the question on the slide. Listen for ideas about developing or using models with SageModeler, agent-based models, or kinesthetic models to generate evidence.

**Brainstorm what the model for Earth systems should include.** Display **slide E**. Say, *We know models can help us generate evidence, but what do our models need to include?* Distribute whiteboards and/or chart paper and markers to each group. Have each group choose one system and write it at the top of their whiteboard. Have each group brainstorm and record components and interactions that we have already investigated in our unit for that system. Then have them describe one way energy and matter flow from this system to or from another. Once students have had time to generate ideas in their small groups, gather the class to create a chart similar to the one below containing all four systems.



|                                                                                   | Atmosphere                                                   | Hydrosphere                                                                           | Biosphere                                                                                                                                               | Geosphere                                                                                         |
|-----------------------------------------------------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| What have we already investigated in our unit?                                    | Fires putting more carbon dioxide into the atmosphere.       | Ice melting in the permafrost.<br><br>Water covering the plants making peat.          | Plants doing photosynthesis.<br><br>Plants, animals, and/or decomposers doing cellular respiration.<br><br>Organisms dying.<br><br>Humans causing fire. | Decomposers in the soil.<br><br>Peat decomposition.                                               |
| What is one way energy and matter flow to or from this system to or from another? | Carbon goes to atmospheres when fires in the biosphere burn. | Carbon goes to the atmosphere when ice melts and decomposers do cellular respiration. | Carbon dioxide goes from the atmosphere to the biosphere when plants do photosynthesis.                                                                 | Carbon goes from the soil in the peat to the atmosphere when decomposers do cellular respiration. |

### 3 · USE A QUANTITATIVE MODEL TO SIMULATE THE FLOW OF CARBON AND ENERGY THROUGH EARTH'S SYSTEMS

20 min

#### MATERIALS: Carbon/Energy Quantitative Model

**Introduce and use the quantitative model.** Say, *I have a model that includes many of those components that I think can help us generate evidence. In this model, you will take on the role of a carbon atom moving through Earth's systems, and we will track the flow of energy and matter as you move.* Display **slide F**. Explain there are seven different locations around the room that represent Earth's systems. Point out to students where you have placed the pre-printed Carbon/Energy Quantitative Model Cards at different locations in your classroom. Explain that students will work their way through the model, starting at the atmosphere, and will move around the room visiting each system, rolling their dice, and following the guidance on the cards. It is important to note that all students begin as a carbon atom in the atmosphere because we are investigating what happens as a result of the added carbon dioxide that ends up in the atmosphere due to fire. \*

**Distribute materials and move to the atmosphere location.** Distribute 1 die, an internet-connected device, access to [https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN\\_easj0mXjXfUkCpMVA/edit?usp=sharing](https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN_easj0mXjXfUkCpMVA/edit?usp=sharing), and *Carbon/Energy Quantitative Model* to each student. Ask each student to make a copy of the spreadsheet. Have all of the students join you at the atmosphere location. The atmosphere is already populated in the first cell since everyone will start there.

**Talk through a sample roll and recording of data.** Display **slide G**. Demonstrate rolling a die and getting the number 5. Show students how to record their data on the spreadsheet. Demonstrate clicking on the drop-downs in each column based on the dice roll at each station. The text on the cards that is underlined corresponds with the drop downs in the matter column and the bold text corresponds with the drop downs in the energy column. If they rolled a 5 in the atmosphere, they would record the following:

Dice roll: 5

Matter: Biomass

Energy: Energy flows to a new system AND the atoms are rearranged.

Next location: Producers

Students can paraphrase what happened at that station in the notes column.

#### \* ATTENDING TO EQUITY

**Support for emergent multilingual learners and other students:** Have students conduct the simulation and *Carbon/Energy Quantitative Model* in pairs, rather than as individuals, with students in each pair sharing the work of reading the instructions, throwing the die, recording the carbon sinks that they visited on the tracking sheet, and telling the story of their carbon atom.

#### \* ATTENDING TO EQUITY

**Universal Design for Learning:** Allowing students to *express* their ideas using multiple modalities supports student ownership of their learning by giving students choice, access, and control in navigating their own understanding around the science ideas.

### ALTERNATE ACTIVITY

If internet-connected devices are not available in your classroom, print *Carbon/Energy Data from Quantitative Model* for each student. They can record the data there and count the totals by hand.

Students will move to each location (following the instructions on the cards) with [https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN\\_easjOmXjXfUkCpMVA/edit?usp=sharing](https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN_easjOmXjXfUkCpMVA/edit?usp=sharing) open on their internet-connected device and use it to record their dice rolls and the subsequent actions for matter and energy at each location. Then students follow the instructions on the card for their previous dice roll and either roll again or move to a new location to roll there. Remind students to mark and record the location and process on the spreadsheet every time they enter a location or roll the dice and remain in that location. Ask the students if they have any questions. They should roll the dice for at least a total total of ten times (rounds).

**Analyze and interpret the data from the simulation.** Display slide H. After students have finished moving around to the different systems, have students total their data from the [https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN\\_easjOmXjXfUkCpMVA/edit?usp=sharing](https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN_easjOmXjXfUkCpMVA/edit?usp=sharing) on *Carbon/Energy Quantitative Model* and interpret it using questions 1 and 2 of the Making Sense questions.



**Make sense of the investigation.** Display slide I. ✱ After students have completed questions 1 and 2, have them share their carbon atom journey (question 3) in groups and then complete the Making Sense questions on *Carbon/Energy Quantitative Model*. Once they have finished sharing, students should individually complete the rest of the Making Sense questions. Remind students that we will discuss this information as a whole class. As students work, have them add their totals to the class data on slide J or a whole-class version of [https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN\\_easjOmXjXfUkCpMVA/edit?usp=sharing](https://docs.google.com/spreadsheets/d/1LQy291YOZmMt1Ax1juzzbTSgN_easjOmXjXfUkCpMVA/edit?usp=sharing). Consider making bar graphs to visualize the totals for location, matter, and energy.

### ADDITIONAL GUIDANCE

When students write the story of their carbon atom, remind them that they played the role of the carbon atom on a journey through a complex system. Encourage them to be creative as they describe the journey they took. They can draw a persona for their atom, describe details of what it looked like, felt like, smelled like, or sounded like to visit each location to join up with different atoms to create molecules or leave them to form other structures. Challenge them to include a time element in their story where they may have gotten stuck and to consider how long that took.

### ALTERNATE ACTIVITY

**Extension Opportunity:** As an expert on the needs of your students, consider alternate modalities that would benefit their learning across all three dimensions. Much of the scaffolding for supporting SEPs and CCCs has been removed at this point in the unit. There are many opportunities for creative expression of the story in the Making Sense questions of *Carbon/Energy Quantitative Model*. You can also consider the following activities as ways to review, extend, or enhance student learning.

Some additional activities to achieve similar learning goals include:

- Energy theater: <https://scholars.spu.edu/representingenergy/energy-representations/energy-theater/>
- Using an modeling online app such as Sage Modeler (used in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them?* (Serengeti Unit): <https://sagemodeler.concord.org/>
- Adding a word bank or sentence stems for the carbon atom story.
- Using images (cutouts, clip art, etc.) to make the task more visual.
- Create a storyboard version of the adventures of the carbon atom.
- Have students do the activity verbally with a scribe.

## 4 · FACILITATE A BUILDING UNDERSTANDINGS DISCUSSION ABOUT THE CARBON ATOM JOURNEY

10 min

Lead a Building Understandings Discussion to reflect on the quantitative model. Display slide K. Gather the class in a Scientists Circle with Carbon/Energy Quantitative Model. \*

## \* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

As in earlier Building Understandings Discussions, make the roles of all participants explicit. Emphasize that you will be pushing for evidence or for connections between our graphs and conclusions, while students may get push-back to their responses to help deepen our understanding.

| Suggested prompts                                                                                               | Sample student responses                                                                                                                                                                                                                                                        | Follow-up questions                                                             |
|-----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Why did all the carbon start out in the atmosphere?                                                             | All the excess carbon dioxide was added to the atmosphere from fire.                                                                                                                                                                                                            | What were we trying to explain with our model?                                  |
| Where did you notice your carbon atom spent more time? What form was it in?                                     | Carbon dioxide in the air/atmosphere and biomass in living and dead organisms.<br><br>In the biosphere, carbon spent the most time as biomass in the producers, then the herbivores, and then the carnivores.                                                                   | Where did your carbon atom spend less time?                                     |
| How did this quantitative model help us explain the flow of energy and matter within and between these systems? | It helped us see that matter and energy move through systems together because when the carbon moved to a different system, the energy moved with it and often changed.<br><br>It helped us see there are many pathways for all the carbon but some are more likely than others. | Were there any limitations or changes you would make to the quantitative model? |

### KEY IDEAS

#### Purpose of this discussion:

- 1) Quantify how carbon moves through each system.
- 2) Motivate the need to develop a model that explains how an increase in carbon in the atmosphere would affect the other systems.

#### Listen for these ideas:

- Carbon visited the atmosphere the most, followed by the producers in the biosphere.
- Carbon was in the form of carbon dioxide the most, followed by biomass.
- Energy flows to other systems, and atoms are rearranged the most.

## ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** See *Carbon/Energy Quantitative Model Key* for guidance. Look for students to quantify/measure the numerical differences in carbon and energy totals from their quantitative model.

**What to do:** Collect *Carbon/Energy Quantitative Model*. Provide feedback using *Carbon/Energy Quantitative Model Key* and return *Carbon/Energy Quantitative Model* with feedback before day 2 of the lesson. In particular, focus on questions 5-7, giving prompts for more specific information on the scale of movement of carbon and energy (How much? How long? How fast?) between spheres. This will help them address complexity on their Gotta-Have-It Checklists on day 2.

**Building toward 9.A** Develop and use a complex, quantitative model that allows for manipulation to describe the flow of carbon (matter) and energy within and between the systems of the hydrosphere, atmosphere, geosphere, and biosphere, through chemical, physical, geological, and biological processes. (SEP: 2.5; DCI: LS2.B.3; CCC: 4.3)

## 5 • NAVIGATE

5 min

MATERIALS: science notebook

Display **slide L**. Say, *We figured out a lot about how the carbon (matter) and energy move through all of the different systems. Let's think about our next steps. In your notebook, using words and/or pictures to predict the effects of the carbon from fires spending most of its time in the atmosphere and biosphere. What will happen in other parts of Earth's systems?*

End of day 1

## 6 • NAVIGATE

5 min

MATERIALS: science notebook

**Check in with a partner.** Display **slide M**. Return *Carbon/Energy Quantitative Model* with feedback. Ask students to review their feedback and check in with a partner to see if they have any questions. Then have students share what they wrote/drew in their notebooks last time. Listen for student ideas about using data from the quantitative model to explain energy and matter flow from system to system but starting with an increase in carbon dioxide. Say, *These are a lot of great ideas! Let's see if we can put them all together to answer our question.*

## 7 • BRAINSTORM COMPONENTS FOR GOTTA-HAVE-IT CHECKLIST

10 min

MATERIALS: science notebook, *Carbon/Energy Quantitative Model*, chart paper, chart paper markers

**Develop a Gotta-Have-It Checklist.** Display **slide N**. Let students know that they will develop a model to answer the question, *How do rising carbon dioxide levels and temperatures from burning carbon sinks affect other Earth systems?* Divide the class into groups of 3-4 students and distribute chart paper or whiteboard and markers to each group. Ask students to work with their groups to make a Gotta-Have-It Checklist that has columns for components, interactions, and mechanisms. Then ask them to populate the columns. Remind students that the purpose of this checklist is to make sure that as a class we have everything we figured out through our investigations accounted for when we make a consensus model to explain how rising carbon dioxide levels and temperatures from burning carbon sinks affect other Earth systems.

## ALTERNATE ACTIVITY

If time permits, and your students need additional scaffolding for the practice of modeling, this is a great opportunity to have them create a global-scale initial model for connections between increased burning, increased temperature, and how matter and energy flow throughout the different systems. They can use their Gotta-Have-It Checklist and group for support during this initial model. Alternatively, have students develop an initial model individually and collect it for comparison later in the unit to see how students' three-dimensional understanding has progressed at the end of the unit Transfer Task.

## 8 · COMPARE AND REVISE GOTTA-HAVE-IT CHECKLISTS

10 min

**MATERIALS:** science notebook, 3x3 sticky notes



**Revise Gotta-Have-It Checklists in groups.** Display **slide O**. Have students remain in their groups to continue to revise and build out their Gotta-Have-It Checklists based on evidence from the quantitative model. Follow the protocol on **slide O** and have two members of each group travel to another group with sticky notes and two members remain at their checklist to share and gather ideas.

### \* ATTENDING TO EQUITY

**Supporting emergent multilinguals:** Priming some groups before a discussion not only signals to them that they are expected to share their ideas in public, but also gives students an opportunity to prepare for it ahead of time. This strategy is particularly effective with quiet students and emergent multilingual students, who will gain confidence from the additional time to organize their ideas before sharing them with others.

## ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** Student checklist with evidence (SEP: 2.3) that includes:

- Photosynthesis pulls carbon dioxide out of the atmosphere, where it can be stored in plants/plantlike organisms in the biosphere. (DCI: LS2.B.3; CCC: 5.4)
- Cellular respiration releases carbon dioxide from living things in the biosphere into the atmosphere. (DCI: LS2.B.3; CCC: 5.4)
- Wildfires that result from human activity release carbon dioxide from carbon stored in carbon sinks into the atmosphere, making it hotter (CCC: 5.4; DCI: ESS2.D.3)
- Energy from the Sun is transferred to carbon dioxide molecules in the atmosphere. (DCI: ESS2.D.3; CCC: 5.4)
- Carbon can be stored out of the atmosphere for long periods of time in carbon sinks created by plants and can be altered by human activity. (CCC: 5.4; DCI: ESS2.D.3)
- More carbon dioxide in the atmosphere leads to higher temperatures, more droughts, more fire, and more carbon dioxide in the atmosphere. (CCC: 5.4; DCI: ESS2.D.3)

**What to do:** As students work, walk around and listen to their conversations. If necessary, use prompts to guide their thinking. Consider carrying a clipboard and recording who you hear from during the Gotta-Have-It Checklist group work to make sure you hear from each student before their individual assessment.

- What conditions in the Lesson 7 models led to more fires?
- How would thawing permafrost show up in the quantitative model?
- Where does the carbon go from \_\_\_\_\_?
- Where does the energy come from to move the carbon?
- How long does the carbon (matter) stay in that system? How quickly does it move?
- How much carbon (matter) is in that system?
- What did we figure out about zombie fires/the peat-permafrost system that could help us understand the flow of carbon (matter) and energy here?
- How does this account for the human actions from the case studies in Lesson 7 that make carbon sinks more likely to burn?
- Where does carbon (matter) go from here?
- Where does the energy go?
- What changes are happening to the system of molecules?
- How would this map to the bottle investigation in Lesson 8?

**Building toward 9.B.1** Develop a model to explain how energy from the Sun and wildfires drives the cycling of carbon, leading to a rise in carbon dioxide concentrations, which affects atmospheric temperatures. (SEP: 2.3; DCI: LS2.B.3; ESS 2.D.3; CCC: 5.4)

How do rising carbon dioxide levels and temperatures from burning carbon sinks affect other Earth systems?

| Components         | Interactions                                                                                 | Mechanisms                                                                                                                                                                          |
|--------------------|----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sun and atmosphere | Carbon dioxide interacts with energy from the Sun in the atmosphere to increase temperature. | The greenhouse effect captures energy from sunlight and transfers it to the atmosphere. More carbon dioxide=more heat. Higher temperatures means more evaporation and more drought. |

|                                                                   |                                                                               |                                                                                                                                                                                                                                                                     |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Carbon sinks in the biosphere (all ecosystems) and the atmosphere | Carbon sinks increase carbon dioxide in the atmosphere.                       | All carbon sinks can burn. The hotter and drier the carbon sinks get as the atmosphere warms, the more likely they are to burn, releasing more carbon dioxide into the atmosphere.<br><br>Burning moves carbon from a carbon sink into the atmosphere very quickly. |
| Carbon sinks in the biosphere (all ecosystems) and the atmosphere | Carbon sinks interact with the atmosphere and increase carbon dioxide.        | When carbon sinks thaw and decompose, they release carbon dioxide into the atmosphere quickly through cellular respiration.                                                                                                                                         |
| Plants, Sun, and carbon sinks                                     | Plants interact with the Sun to make carbon sinks, decreasing carbon dioxide. | Plants undergo photosynthesis, using energy from the Sun to grow trees and grasses that become carbon sinks that store carbon out of the atmosphere.<br><br>Plants, especially trees, can store carbon for decades or centuries.                                    |
| Water in the hydrosphere and carbon sinks                         | Carbon sinks that lose water increase carbon dioxide.                         | As carbon sinks dry out because of human action or higher temperatures, they are more likely to burn.                                                                                                                                                               |

**Review checklist in small groups.** Display **slide P**. Remind students that their goal is to help each other make sure everyone in their group is prepared to share in the upcoming whole-class discussion. Have students share what they figured out from visiting other groups and add or revise their checklists.\*

## 9 • DEVELOP A CLASS CONSENSUS MODEL

15 min

**MATERIALS:** science notebook, chart paper, chart paper markers



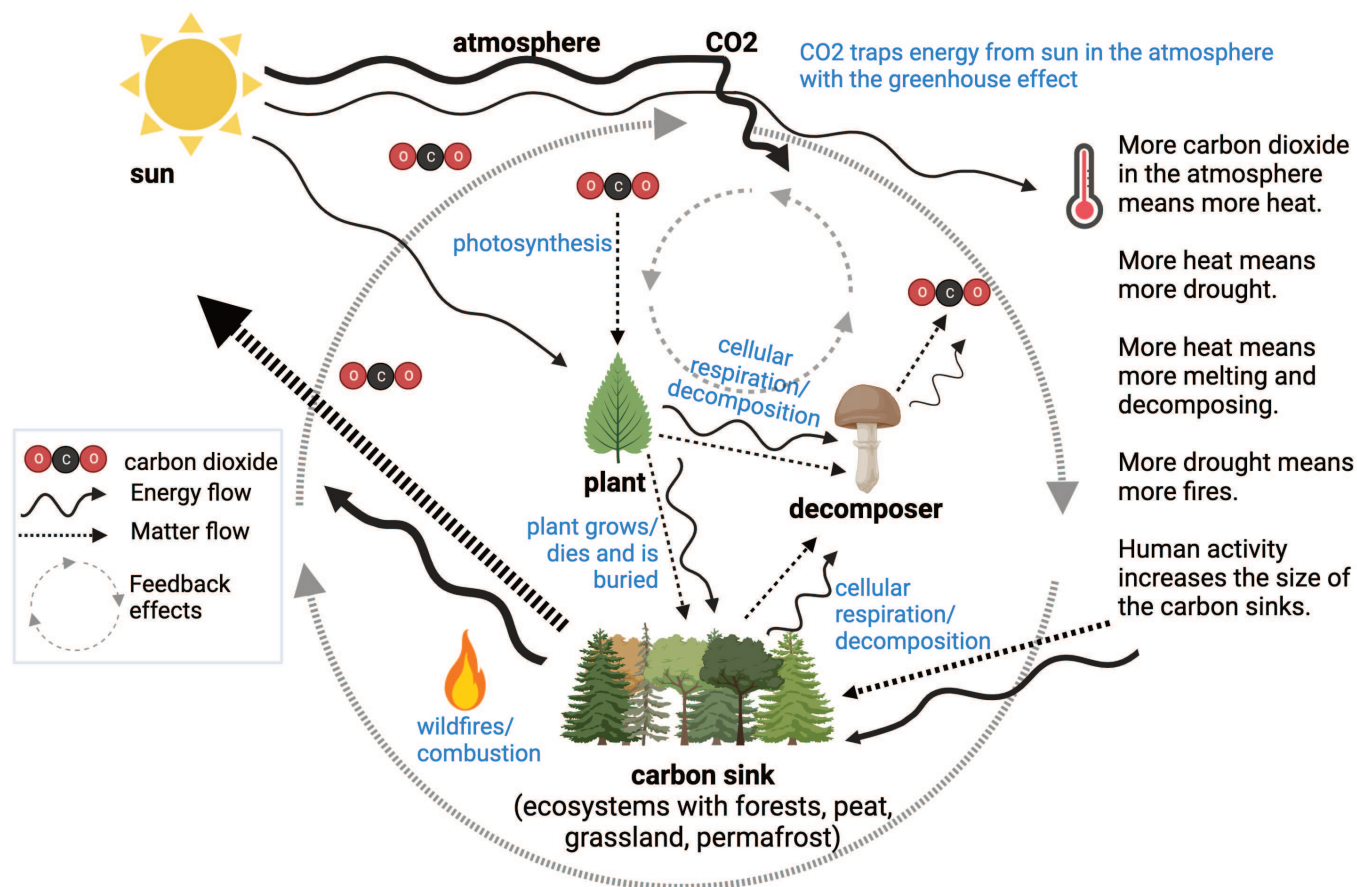
**Develop a class consensus model.** Display **slide Q**. Ask students to bring their completed Gotta-Have-It Checklists as they gather in a Scientists Circle. Say, *Let's figure out how we can develop a model for how rising carbon dioxide levels and temperatures from burning carbon sinks affect other Earth systems using your checklists.*

On a piece of chart paper, develop a class consensus model. One example is shown below. There are many different ways students can express their ideas in the model, and it is important to follow student suggestions to guide the construction of the model.

### \* STRATEGIES FOR THIS CONSENSUS DISCUSSION

While facilitating this discussion, elicit ideas from students that build on other students' ideas by prompting the class with *Do we all agree with that?* or *How are these explanations similar? How are they different?* Invite support and critique by asking *Who has ideas not represented here?* or *Are there still places we disagree?* Let the class struggle with ways to interpret the model. This is not an easy thing





Illustrations created by OpenSciEd in BioRender

Throughout the discussion, remind students to record any questions they have in their science notebooks so that they do not lose those questions. They will have a chance to add them to the DQB at the end of class. \* \*

### Suggested prompt

*How are the boundaries of this new global system different from the models we discussed in earlier lessons?*

### Sample student response

Now our boundary is all of Earth's systems, not just the atmosphere or one ecosystem.

to do and it is a great opportunity for the class to work together to build on the ideas brought forth during the discussion.

### \* ATTENDING TO EQUITY

**Universal Design for Learning:** Use *representations* like color coding and/or letter or number coding to foreground parts of the model. Create a key to track what colors, symbols, or letter or number codes represent different parts of the system. While color coding is a useful way to quickly reference the parts of the model, letter or number coding helps ensure accessibility for any student who may be color blind. If color coding is used, consider a color palette that uses orange, blue, black, or dark brown.



| Suggested prompt                                                                                                                                                                                                                                    | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What scales should we include in our global model?</i>                                                                                                                                                                                           | <p>We have three different scales we need to make sure we include:</p> <p>Global-scale Earth systems—going from one system to another.</p> <p>Ecosystem—carbon (matter) and energy through different matter locations.</p> <p>Atomic-molecular—following carbon (matter) and energy through chemical processes—photosynthesis, digestion, cellular respiration where systems of molecules are rearranged.</p>                                                           |
| <i>Look at your checklists. What are some components, interactions, and mechanisms we can start with in our global model for explaining how rising carbon dioxide levels and temperatures from burning carbon sinks affect other Earth systems?</i> | <p>Photosynthesis</p> <p>Cellular respiration</p> <p>Wildfires</p> <p>Carbon sinks</p> <p>The greenhouse effect</p>                                                                                                                                                                                                                                                                                                                                                     |
| <i>What evidence do we have that supports the components and mechanisms we want to add to our model?</i>                                                                                                                                            | <p>Data from the bottle investigation.</p> <p>Graphs showing global temperature and carbon dioxide levels rising together.</p> <p>Examples of burning carbon sinks from previous lessons.</p> <p>Differences in BTB color changes from burning and photosynthesis.</p>                                                                                                                                                                                                  |
| <i>Now that our model has all of the parts we want, can we use it to explain our lesson question: How do rising carbon dioxide levels and temperatures from burning carbon sinks affect other Earth systems?</i>                                    | <p>Yes, we can see that as these carbon sinks burn, they release more and more carbon into the atmosphere.</p> <p>If there is more and more carbon dioxide in the atmosphere, there will be more in other spheres as well.</p> <p>More carbon dioxide in the atmosphere increases the greenhouse effect, which warms the Earth more.</p> <p>Rising temperatures cause more drought, which leads to more fires and more release of carbon dioxide from carbon sinks.</p> |

## KEY IDEAS

### Purpose of the discussion:

- To formally develop a model connecting three scales of cycling of carbon and energy: micro-level, ecosystem, and global-scale Earth systems.
- To recognize the feedback effect created by this system that builds up carbon dioxide in the atmosphere.

### Listen for these ideas:

The mechanisms involved in this model include:

- Photosynthesis pulls carbon dioxide out of the atmosphere, where it can be stored.
- Cellular respiration releases carbon dioxide from living things into the atmosphere.
- Wildfires release carbon dioxide from carbon stored in carbon sinks into the atmosphere very quickly.
- Energy from the Sun is transferred to carbon dioxide molecules in the atmosphere, and this greenhouse effect warms the Earth.
- Carbon can be stored out of the atmosphere for long periods of time in carbon sinks created by plants.
- The warming atmosphere increases droughts and thaws permafrost and other ice.
- More droughts lead to more wildfires.
- The model needs to be generalized for all wildfires and all plant-based carbon sinks.
- It is difficult to model the amount of carbon dioxide in the atmosphere because it keeps changing and growing. There is a cycle that builds up carbon dioxide over time.

**Update Personal Glossaries.** Display slide R. Introduce the definitions of the carbon cycle and feedback effects below as the need arises in your development of the consensus model. If the need does not arise naturally, point out the looping connections in the consensus model. Say, *We co-constructed a couple of new ideas here. You all found these loops or circles in the model. What connected them?* Listen for responses such as carbon and energy. *Scientists call these loops that show how carbon moves around “the carbon cycle.”* Ask students to co-construct a definition of the carbon cycle and add it to their Personal Glossaries.

**Co-construct definition of feedback effects.** As it comes up in the consensus discussion, point out the loops in the model that increase carbon dioxide in the atmosphere. Ask, *What did we figure out about whether the carbon dioxide and temperature levels would keep rising or level off? Why?* *Scientists call these loops or circles “feedback effects.”*

## ADDITIONAL GUIDANCE

The carbon cycle moves carbon between the atmosphere and biosphere (and geosphere) through combustion (burning), photosynthesis, and cellular respiration. Additional mechanisms are discussed in *Oysters Unit* and *Fuels Unit*. Carbon may be found in different molecular forms in different parts of the cycle (e.g., carbon dioxide, glucose, and starch), but the same atoms pass through the system over and over again.

Use students' own descriptive words to facilitate this discussion. Feedback occurs when what is created in one part of a system becomes a source for an effect in another part of the system and the whole system moves away from a set point or stable state. In this case, carbon dioxide increases in the atmosphere, which makes it hotter, increasing the number, duration, and intensity of fires in ecosystems, which adds more carbon dioxide to the atmosphere.

## ALTERNATE ACTIVITY

**Extension Opportunity:** If students become curious during the consensus discussion about how this might look to actually see these changes happening on a global scale OR need help to visualize, consider either showing the class the following visualization or allowing them time to notice and wonder about it on individual or small-group internet-connected devices: The link to this visualization is: <https://svs.gsfc.nasa.gov/5110>.

**MATERIALS:** internet-connected device, <https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8JH3RBgVLKqLv9h48WoEaL7TA6Q/copy>, Related Phenomena poster, DQB, 3x3 sticky notes, chart paper markers

**Navigate to the next lesson.** Display slide S. Bring the class back together to share. Ask students some of their questions. Listen for students to tell you that increasing carbon and temperature is disturbing and they want to do something about it.

### \* ATTENDING TO EQUITY

**Universal Design for Learning:** Use this opportunity to revisit or identify new examples of phenomena from students' own contexts. Highlight examples that involve interruptions or imbalances in their own communities, similar to what we think is happening in the quantitative model for carbon in Earth's systems. This move can increase student *engagement* by broadening the class mission to explain not only increasing temperatures around the world, zombie fires, or fires around the world phenomena but also familiar everyday phenomena in students' lives.

| Suggested prompt                                                                                                               | Sample student response                                                                                                                                                                                                                                                                                                        |
|--------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Are there any questions from our DQB or ideas from our Related Phenomena poster that we want to revisit at this time? *</i> | We want to know more about how to help!                                                                                                                                                                                                                                                                                        |
|                                                                                                                                | We want to know more about our communities.                                                                                                                                                                                                                                                                                    |
| <i>What are some questions you have now?</i>                                                                                   | How can we reduce the number of carbon sinks that are burning?                                                                                                                                                                                                                                                                 |
|                                                                                                                                | Can we plant more trees to take in more carbon from the atmosphere to balance out the cycle?                                                                                                                                                                                                                                   |
|                                                                                                                                | Some of the case studies from the last lesson mentioned that some ecosystems are fire-adapted. Could we plant more of those ecosystems?                                                                                                                                                                                        |
|                                                                                                                                | People seem to be causing a lot of the fires. What could people do to stop the fires?                                                                                                                                                                                                                                          |
|                                                                                                                                | How can we protect the carbon sinks from burning?                                                                                                                                                                                                                                                                              |
| <i>Why does this matter to you? Us? The world?</i>                                                                             | Burning carbon sinks have a large-scale impact on the planet. We've had really hot summers here, and there have been some fires because of the drought. I'm concerned about this getting worse. It is scary that temperatures keep rising. I'm starting to understand how small-scale actions can have big-scale consequences. |
| <i>What do you think would be productive for our classroom community to investigate next?</i>                                  | Increasing temperature and carbon are disturbing. We want to find a solution or way to make it better.                                                                                                                                                                                                                         |
|                                                                                                                                | We need to know if there are places where people are doing things to help stop the fires from releasing so much carbon or to reduce the amount of carbon they release.                                                                                                                                                         |

If there are any new questions, have students record them on a sticky note with their initials and L9 on the back and add them to the DQB. This will help you see that these are new questions from individual students from this lesson. Students may also add new related phenomena to add to the Related Phenomena poster.

## ADDITIONAL GUIDANCE

If students need prompting, encourage them to think across scales and how smaller-scale processes are part of larger systems that have global impacts. To prompt more questions, ask them to consider how the relationships and mechanisms we learned in this and previous lessons might possibly control or slow down the positive feedback cycle they saw in their model. Additionally, if students struggle to come up with questions, have them walk over to the DQB and see which questions we have yet to answer.



**Complete an exit ticket.** Display slide T. Say, *Thank you for sharing all of those ideas. We figured out some pretty important things about how humans and fires are affecting the feedback effects for matter and energy in the global carbon cycle. Let's take a moment to record our current understanding.*

Have students complete <https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8JH3RBgVLKqLv9h48WoEaL7TA6Q/copy>. Encourage students to use their notes to help them answer the questions on the Electronic Exit Ticket. See *Exit Ticket Guidance* for instructions on how to make the Electronic Exit Ticket.

## ASSESSMENT OPPORTUNITY

**What to look/listen for in the moment:** See *Electronic Exit Ticket Key* for guidance.

**What to do:** See *Electronic Exit Ticket Key* for guidance.

**Building toward 9.B.2** Develop a model to explain how energy from the Sun and wildfires drives the cycling of carbon, leading to a rise in carbon dioxide concentrations and atmospheric temperatures. (SEP: 2.3; DCI: ESS 2.D.3; CCC: 5.4)

# Additional Lesson 9 Teacher Guidance

## SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

**CCSS.MATH.CONTENT.HS.N-Q.2**

Quantities: Reason quantitatively and use units to solve problems.  
Define appropriate quantities for the purpose of descriptive modeling.

Students do descriptive modeling by aggregating their matter and energy data collected from visiting each subsystem into tables and comparing the number of times a subsystem was visited, the type of carbon-based molecule, length of time in that type/system, as well as indicators of energy and number of occurrences.

## SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

**CCSS.ELA-LITERACY.RST.9-10.7** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Students build a quantitative model using written information about carbon atoms. They then use the data collected in the quantitative model to write the journey of their carbon atom.



# LESSON 10: How can we help manage the matter and energy in fire systems?

**PREVIOUS LESSON** We used a quantitative model to simulate how carbon and energy flow through Earth's systems. We developed a Gotta-Have-It Checklist and consensus model to explain the implications of rising carbon dioxide levels and temperatures on Earth's systems. We decided to investigate ways to manage carbon sinks to reduce feedback effects from climate change in relation to fires.

## THIS LESSON

### INVESTIGATION

3 days



Isa Toberman & Todd Levine

We investigate four case studies of fire management. We read about how prescribed burning, cultural burning, restoring grazer populations, and replanting forests help manage the amount of available carbon and energy that could burn in wildfires. We develop a mathematical representation to explain how these techniques could alter the flow of energy and matter in these ecosystems. We investigate fire risk in our own community and begin to define a plan for reducing that risk.

**NEXT LESSON** We will design fire management solutions for places, lands, and waters in our community, break down fire management criteria, identify constraints, and design systems. We will close the Driving Question Board and revisit our Progress Trackers.

## BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



## WHAT STUDENTS WILL DO

**10.A** Apply scientific reasoning to link evidence behind approaches to fire management to support explanations about the flow of matter and energy through different levels of the ecosystem. (SEP: 6.4; DCI: LS2.B.2, CCC: 5.3)

**10.B** Use mathematical representations to support claims about the cycling of matter and flow of energy among organisms in an ecosystem. (SEP: 5.2; DCI: LS2.B.2, CCC: 5.3)

**10.C** Define the need for a plan to reduce the risk of wildfire in a community of concern and the social and environmental components that make the system likely to burn. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)

## WHAT STUDENTS WILL FIGURE OUT

- Managing the amount of fuel available to burn in carbon sinks through prescribed burns, cultural burns, and grazing helps reduce an overabundance of built-up energy and matter.
- Planting trees can remove carbon dioxide from the atmosphere and has the potential to reduce atmospheric temperature.
- Energy and matter flow through each level of a food web through producers, consumers and decomposers..
- Fire management decisions have short- and long-term consequences for both social and ecological structures and systems.

## Lesson 10 • Learning Plan Snapshot

| Part                | Duration |                                                                                     | Summary                                                                                                                                                                                                                       | Slide | Materials                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------|----------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                   | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Students review what they figured out in the previous lesson and share feelings about what they figured out.                                                                                               | A-B   |                                                                                                                                                                                                                                                                                                                                                                                             |
| 2                   | 18 min   |    | <b>INVESTIGATE SUCCESSFUL FIRE MANAGEMENT</b><br>Organize groups to investigate case studies of successful fire management.                                                                                                   | C-E   | copy of Lesson 9 consensus model, <i>Prescribed Burn Case Study</i> , <i>Grazing Case Study</i> , <i>Cultural Burn Case Study</i> , <i>Tree Planting Case Study</i> , <i>Fire Management Study</i> , internet-connected device for groups reading <i>Prescribed Burn Case Study</i> and <i>Cultural Burn Case Study</i> , <i>Responses to Case Studies</i> , <i>UDL for Jigsaw Readings</i> |
| 3                   | 15 min   |                                                                                     | <b>SHARE FIRE MANAGEMENT CASE STUDIES</b><br>Facilitate sharing of case studies in new groups of students.                                                                                                                    | F     | <i>Fire Management Study</i> , copy of Lesson 9 consensus model, <i>Responses to Case Studies</i> , <i>Community Agreements</i> (optional)                                                                                                                                                                                                                                                  |
| 4                   | 7 min    |                                                                                     | <b>NAVIGATE: REFLECT ON CASE STUDIES</b><br>Reflect on similarities and differences between case studies. Raise questions about whether planting trees is enough for an ecosystem to recover.                                 | G-I   | <i>Responses to Case Studies</i> , chart paper, chart paper markers                                                                                                                                                                                                                                                                                                                         |
| <i>End of day 1</i> |          |                                                                                     |                                                                                                                                                                                                                               |       |                                                                                                                                                                                                                                                                                                                                                                                             |
| 5                   | 3 min    |                                                                                     | <b>NAVIGATE</b><br>Reflect on the effectiveness of replanting trees as a restoration technique.                                                                                                                               | J     |                                                                                                                                                                                                                                                                                                                                                                                             |
| 6                   | 5 min    |                                                                                     | <b>RECALL COMPONENTS OF THE SERENGETI ECOSYSTEM</b><br>Revisit the Serengeti ecosystem with a matter and energy lens.                                                                                                         | K     | <i>MakingSense Serengeti Fire</i> , whiteboard, dry erase markers                                                                                                                                                                                                                                                                                                                           |
| 7                   | 10 min   |                                                                                     | <b>MAKE SENSE OF ENERGY AND MATTER IN THE SERENGETI</b><br>Organize students for individual reading and small-group sensemaking.                                                                                              | L-O   | <i>Fire in Serengeti</i> , <i>MakingSense Serengeti Fire</i>                                                                                                                                                                                                                                                                                                                                |
| 8                   | 12 min   |  | <b>USE A MATHEMATICAL REPRESENTATIONS OF ENERGY AND MATTER IN THE SERENGETI</b><br>Support students in modeling energy and matter flow in the Serengeti.                                                                      | P-Q   | <i>Fire in Serengeti</i> , <i>MakingSense Serengeti Fire</i>                                                                                                                                                                                                                                                                                                                                |
| 9                   | 10 min   |                                                                                     | <b>BUILDING UNDERSTANDINGS: CONNECT MATTER AND ENERGY CYCLING TO FIRE MANAGEMENT</b><br>Facilitate a Building Understandings Discussion about matter, energy, and fire management techniques in the context of the Serengeti. | R     | <i>Fire in Serengeti</i> , <i>MakingSense Serengeti Fire</i>                                                                                                                                                                                                                                                                                                                                |

| Part                | Duration |                                                                                   | Summary                                                                                                                                                                                                                                                                 | Slide | Materials                                                                                                                                                    |
|---------------------|----------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10                  | 5 min    |                                                                                   | <b>NAVIGATE: UPDATE PROGRESS TRACKER</b><br>Students update their Progress Trackers.                                                                                                                                                                                    | S     | <i>Fires Progress Tracker</i>                                                                                                                                |
| <i>End of day 2</i> |          |                                                                                   |                                                                                                                                                                                                                                                                         |       |                                                                                                                                                              |
| 11                  | 5 min    |                                                                                   | <b>NAVIGATE</b><br>Review ways fire can be beneficial to ecosystems.                                                                                                                                                                                                    | T     |                                                                                                                                                              |
| 12                  | 15 min   |                                                                                   | <b>DISCUSS THE VALUE OF SHARING KNOWLEDGE FROM MULTIPLE CULTURES FOR MANAGING FIRE</b><br>Watch the case study video from Victoria and facilitate a discussion of the value of collaborations between peoples holding different types of knowledge for fire management. | U-Y   |                                                                                                                                                              |
| 13                  | 20 min   |  | <b>CONNECT TO RELATED PHENOMENA</b><br>Investigate the fire risk in communities of interest to students. Discuss possible ways to reduce the fire risk.                                                                                                                 | Z-BB  | <i>Fire Risk Home-Learning</i> , internet-connected device, chart of wonderings from day 1, Related Phenomena poster from Lesson 1, DQB, chart paper markers |
| 14                  | 5 min    |                                                                                   | <b>NAVIGATE: INTRODUCE HOME LEARNING</b><br>Discuss how to share what we learned with members of the community and gather ideas for fire management.                                                                                                                    | CC    | <i>Fire Risk Home-Learning</i>                                                                                                                               |
| <i>End of day 3</i> |          |                                                                                   |                                                                                                                                                                                                                                                                         |       |                                                                                                                                                              |



## Lesson 10 • Materials List

|                  | per student                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | per group                                                                                                                                                                                                                                              | per class                                                                                                                                                                                                                                                                                                                  |
|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson materials | <ul style="list-style-type: none"> <li>science notebook</li> <li>copy of Lesson 9 consensus model</li> <li><i>Prescribed Burn Case Study</i></li> <li><i>Grazing Case Study</i></li> <li><i>Cultural Burn Case Study</i></li> <li><i>Tree Planting Case Study</i></li> <li><i>Fire Management Study</i></li> <li><i>MakingSense Serengeti Fire</i></li> <li><i>Fire in Serengeti</i></li> <li><i>Fires Progress Tracker</i></li> <li><i>Fire Risk Home-Learning</i></li> </ul> | <ul style="list-style-type: none"> <li>internet-connected device for groups reading <i>Prescribed Burn Case Study</i> and <i>Cultural Burn Case Study</i></li> <li>whiteboard</li> <li>dry erase markers</li> <li>internet-connected device</li> </ul> | <ul style="list-style-type: none"> <li><i>Responses to Case Studies</i></li> <li><i>UDL for Jigsaw Readings</i></li> <li>Community Agreements (optional)</li> <li>chart paper</li> <li>chart paper markers</li> <li>chart of wonderings from day 1</li> <li>Related Phenomena poster from Lesson 1</li> <li>DQB</li> </ul> |

### Materials preparation (10 minutes)

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

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

Be sure your Community Agreements are visible for reference during this lesson.

Three-hole-punch all handouts so they can be added to student notebooks. On day 1, print copies of each case study (*Prescribed Burn Case Study*, *Grazing Case Study*, *Cultural Burn Case Study*, *Tree Planting Case Study*) for students to read. Each student will only need a copy of one case study.

Provide an internet-connected device for each group reading *Prescribed Burn Case Study*, and *Cultural Burn Case Study* on days 1 and 3.

Make copies for each group of the Lesson 9 consensus model to revise on day 1.

Gather whiteboards and dry erase markers for groups of 2-3 students for day 2.

## Lesson 10 • Where We Are Going and NOT Going

### Where We Are Going

In this lesson, students relate what they know about the flow of energy and matter in Earth's systems to fire management techniques and investigate those techniques in a familiar ecosystem, the Serengeti.

Students draw on their MS understanding about food webs from MS LS2.B to build toward a complete understanding of the following HS DCI: *Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.* (LS2.B.2)

Students build on their use of the science practice *constructing explanations* from Lesson 5 and their use of *mathematics and computational thinking* from *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them?* (Serengeti Unit). They *define problems* in a new way as they consider the implications of fire management techniques.

Students develop their use of the crosscutting concept *energy and matter* and draw on middle school ideas about the conservation of energy and matter. These ideas will be further developed in OpenSciEd Chemistry and Physics. Students build on their use of *systems and system models* from *Serengeti Unit*

### Where We Are NOT Going

There are other methods of successful fire management not explored through the four case studies, including developing fire breaks with materials (soil, rock, water systems) and forms of fire-safe landscaping and building materials.

Although fire management solutions have implications for larger-scale change related to the systems discussed in Lesson 9, those changes are not explicitly discussed in this lesson. The focus of this lesson is on how the short-term dynamics within ecosystems are impacted by successful fire management rather than the long-term shifts in those same ecosystems as a result of climate change.

# LEARNING PLAN for LESSON 10

## 1 · NAVIGATE

5 min

MATERIALS: science notebook

Review what we figured out in the last lesson. Display slide A. Ask students to turn and talk about the questions on the slide.

Whole-class share. Display slide B. Choose 3 students and ask each student to respond to one of the prompt questions. \*

| Suggested prompt                                                                           | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| What did we figure out about global wildfires and Earth's systems in the last few lessons? | <p>Burning carbon sinks moves carbon from stores in the Earth to carbon dioxide in the atmosphere and the biosphere.</p> <p>More carbon dioxide in the atmosphere traps heat, warming the Earth.</p> <p>This warming causes more drought in some places, which then can cause more wildfires.</p> <p>This warming can also cause melting. We see this in peatlands in permafrost melting.</p> <p>When the peatlands defrost, cellular respiration in decomposers begins again and moves carbon into the atmosphere.</p> <p>Human actions make carbon sinks even more vulnerable to this positive feedback effect.</p> |
| How do you feel about what we figured out in the last few lessons?                         | <p>Accept all responses. Listen for students wanting to take action.</p> <p>Acknowledge and provide support to students who are scared, concerned, disheartened.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

Validate student responses. Justify all student feelings at this time. Emphasize that while increased temperature and carbon in the atmosphere are making wildfires harder to fight, we want to have hope for the future and take action.

### \* ATTENDING TO EQUITY

This introductory discussion is important in order to reinforce the understanding that expertise about wildfires exists in many places and that many sources of knowledge are important in making decisions about how to manage these fires. It also addresses the nature of science by reminding students that science knowledge can help us understand natural systems, but making decisions about how to use that knowledge requires us to think about ethics and values. This is also a good place to encourage students to think about how the solutions we design would affect the people who are most impacted by the problem. Rather than coming in to solve a problem for them, science can be used together with the knowledge of impacted people to develop a more effective solution.

## 2 · INVESTIGATE SUCCESSFUL FIRE MANAGEMENT

18 min

**MATERIALS:** science notebook, copy of Lesson 9 consensus model, *Prescribed Burn Case Study*, *Grazing Case Study*, *Cultural Burn Case Study*, *Tree Planting Case Study*, *Fire Management Study*, internet-connected device for groups reading *Prescribed Burn Case Study* and *Cultural Burn Case Study*, *Responses to Case Studies*, *UDL for Jigsaw Readings*

**Motivate a discussion of solutions to manage fires.** Display **slide C**. Ask students to recall the case studies they read about in Lesson 7 and the possible solutions they came up with for those scenarios. Direct them to revoice questions from the DQB or *Fires Progress Tracker* about ways to manage or reduce the burning of carbon sinks.

| Suggested prompt                                                                      | Sample student response                                                                                                                              |
|---------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| What questions did we have about protecting carbon sinks from burning?                | Could we bring Indigenous burning practices to more places?<br>Should the government stop the fire suppression policies?                             |
| What ideas did you have for possible solutions to protect the carbon sinks from fire? | Accept all responses. Some might include:<br>Expand cultural burning.<br>Stop people from moving into the forests.<br>Stop building dams and canals. |

Say, *Thank you for sharing these ideas. They bring me hope that if we figure out more about them that we might be able to design some solutions and take action!*

**Introduce the investigation.** Display **slide D**. Explain that you found some examples of the kinds of solutions students proposed and that we are going to spend today investigating different cases of ways to manage carbon sinks that have been or could be impacted by fire. \*\*

- Organize the class into 8 groups of 3-5 students so that there are 2 student groups working with each of the four case studies. Students will return to these same groups on day 2. Distribute a picture of the Lesson 9 consensus model and *Fire Management Study* to each student.
- Distribute one of the following to each student based on their group: *Prescribed Burn Case Study*, *Grazing Case Study*, *Cultural Burn Case Study*, or *Tree Planting Case Study*.

**Read management case studies.** Display **slide E**. Explain to students that they will have 15 minutes in their groups. As they read, students can use the literacy strategies in place in your district/school, or they can apply the Reading for Gist method found in the *OpenSciEd Teacher Handbook: High School Science*. Working together, students should complete *Fire Management Study* to make sense of the information in their case study. Students should support one another in understanding the reading so that all students are prepared to teach others in the class the main takeaways from the study.\*

### \* ATTENDING TO EQUITY

**Universal Design for Learning:** You may wish to allow students to self-select readings based on interest, before dividing them into groups. Or for this activity, students can choose which text to read based on difficulty. *Cultural Burn Case Study* is most accessible, while *Prescribed Burn Case Study* is most challenging. You can read more about the text adaptations and text-specific suggestions in *UDL for Jigsaw Readings*.

## ALTERNATE ACTIVITY

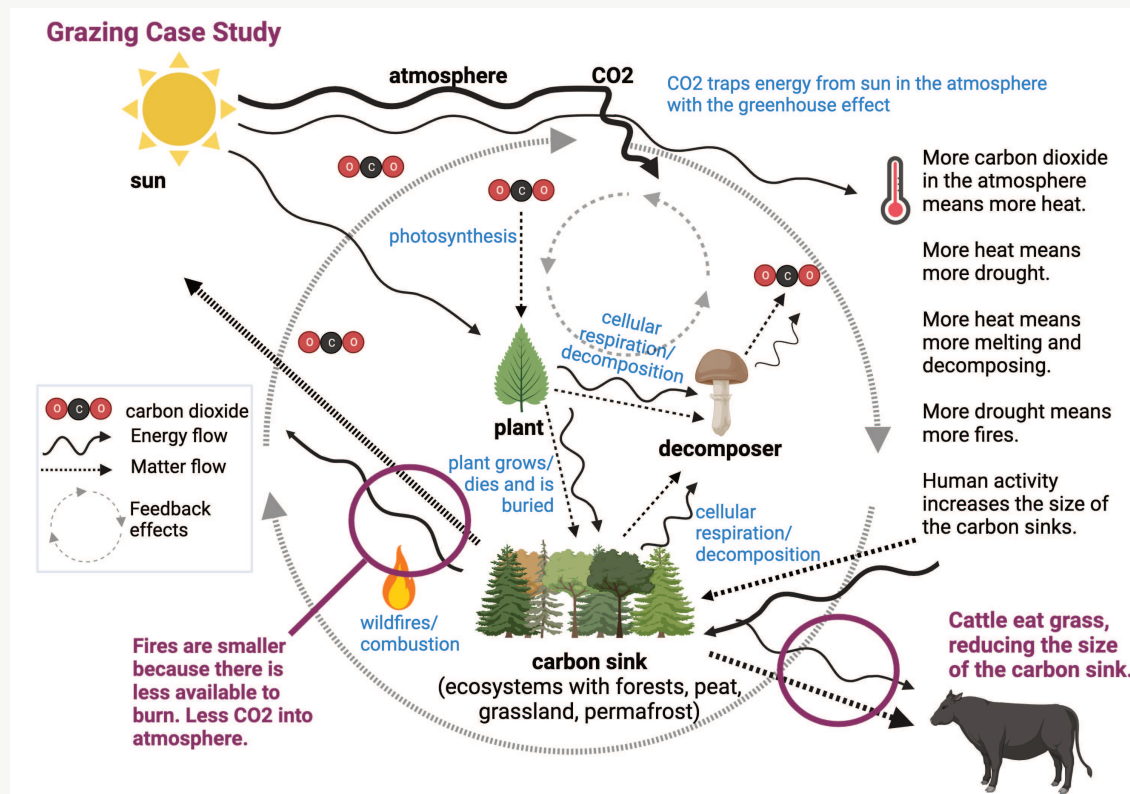
If there is another region you believe would generate higher interest for your students, exchange it for an existing case study. If you make a change, make sure you retain the following 4 focal areas:

- Use of grazing animals to prevent fires.
- Use of prescribed burning to prevent fires.
- Use of cultural burning by an Indigenous group in partnership with a governmental or non-Indigenous group.
- Restoration project to plant trees or other plants with potential to sequester large amounts of carbon following a large wildfire.

For students interested in cultural burning practices that follow-up on *California's Carbon Sink*, the Karuk Nation has a series of short videos about their programs. <https://vimeo.com/458221338>



**Support small-group discussion.** Guide students while they discuss their case study in groups by telling them to relabel/revise their copies of the Lesson 9 consensus model describing how the form of management of carbon sinks they read impacts the flow of energy and matter and/or positive feedback effects. An example of how students might revise the Lesson 9 consensus model follows.



Illustrations created by OpenSciEd in BioRender

## ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** Scientific reasoning that supports an explanation (SEP: 6.4) for each case study as they revise their Lesson 9 consensus models:

- Prescribed Burn Case Study and Cultural Burn Case Study: Prescribed burning reduces the amount of carbon and energy (fuel) in the carbon sink available to burn. (DCI: LS2.B.2; CCC 5.3)
- Grazing Case Study: Adding grazers to the model reduces the amount of carbon and energy (fuel) available to burn because some of it moves from plants into animals. (DCI: LS2.B.2; CCC 5.3)
- Tree Planting Case Study: Planting trees moves carbon and energy from the atmosphere into the trees. (DCI: LS2.B.2; CCC: 5.3)

**What to do:** Circulate around the room to formatively assess students' revisions. Bring your class roster and mark off when you hear a student correctly apply scientific reasoning to link evidence from their case study to the revised model. *Responses to Case Studies* is a guide summarizing the main points of each case. Use the following prompts with groups:

- What happens to the carbon and energy in this ecosystem? How do you know?
- Prescribed Burn Case Study and Cultural Burning Case Study: How could setting a fire on purpose help manage wildfires? What is and is not burning in this method compared to a wildfire?
- Grazing Case Study: What are the cattle eating? Is what the cattle eats the same material that burns during a wildfire? How does the energy and matter flow in the system when grazers are introduced?
- Tree Planting Case Study: How does planting trees affect the flow of energy and matter?
- If students have questions or comments related to power and historicity in the case study, encourage them to record their ideas in their notebooks for discussion on day 3.
- Remind students of the fire triangle they investigated in Lesson 2 and ask them to think about how the solution alters the triangle but reduces fuel and possibly heat by reducing the amount of carbon dioxide in the atmosphere.
- To lead into the discussion on day 2 of the lesson, encourage questions about quantifying how much must be burned or eaten to have a positive impact.

**Building toward 10.A** Apply scientific reasoning to link evidence behind approaches to fire management to support explanations about the flow of matter and energy through different levels of the ecosystem. (SEP: 6.4; DCI: LS2.B.2, CCC: 5.3)

## 3 · SHARE FIRE MANAGEMENT CASE STUDIES

15 min

**MATERIALS:** *Fire Management Study*, copy of Lesson 9 consensus model, *Responses to Case Studies*, Community Agreements (optional)

**Share fire management case studies in new groups.** Display slide F. Form new groups of 3-5 students so that at least one representative from each case study group is present. Ask the representatives to take 3 minutes to share what they figured out from their case studies with the new students in their groups, including any changes they made to the Lesson 9 consensus model, focusing on how the solution alters the flow of energy and matter. Ask students listening to answer the questions on part 3 of *Fire Management Study* and make edits to their own copy of the Lesson 9 consensus model. Remind students to switch to the next group member every 3 minutes so all four case studies are presented within each group. Walk around and listen to groups to assess that they communicate this knowledge to their group members. Use *Responses to Case Studies* as a guide for discussion. If students have questions or comments related to power and historicity in the case studies, encourage them to record their ideas in their notebooks for discussion on day 3. \*

## ADDITIONAL GUIDANCE

Students begin this activity by talking to someone they did not work with on their case study. This provides students with the opportunity to hear or think about more than one perspective on managing carbon sinks impacted by fire. They will use what they figured out to begin to understand the complexities of fire management in this lesson and use the ideas for further inspiration for designing solutions in Lesson 11.

## \* ATTENDING TO EQUITY

**Building classroom culture and norms:** This is an important opportunity to emphasize that each individual has contributions to make to their community of learners. It is through differences in thinking that the class will grow their knowledge together. Throughout this unit, students will be asked to be open to sharing knowledge products that depict their current thinking and to be open to learning from classmates who share

their knowledge too. If useful, revisit your Community Agreements to emphasize these ideas.

## 4 · NAVIGATE: REFLECT ON CASE STUDIES

7 min

**MATERIALS:** science notebook, *Responses to Case Studies*, chart paper, chart paper markers

**Share what students figured out.** Display **slide G**. Ask three students to share a generalized reflection on what they figured out today with the class using the slide prompts. Focus on the cycling of carbon (matter) and energy for this conversation, holding analysis of other parts of the technique until discussion on day 3. Listen for students to mention that:

- Two case studies involve burning on purpose to reduce the amount of fuel/size of the carbon sink.
- Three of the case studies involve removing plant material to reduce available fuel and prevent fire.
- One involves planting to restore trees and take carbon dioxide out of the atmosphere.

**Reflect on new ideas.** Display **slide H**. Provide a minute for students to silently reflect on the prompts on the screen.

- How do you feel about what you figured out from these case studies?
- What questions do you have about the effectiveness of these management techniques?

**Reflect on the effectiveness of management techniques.** Explain to students that the class will spend more time discussing the effectiveness of these different management techniques and you want to hear some of their wonderings. Ask a few students to share some of their wonderings. Record the questions on chart paper to use on day 3 of this lesson. If no student raises the following questions on their own, add your own wonderings to the student list:

- How much plant matter needs to be burned for a prescribed or cultural burn to be effective?
- Would the trillion tree project be enough to make a difference for carbon dioxide in the atmosphere?
- How do we know how many grazers to have in an area?

**Individual reflection about managing energy and matter flow in an ecosystem.** Display **slide I**. Celebrate students' thoughtful questions. Then ask students to think about one big idea from their list in the context of matter and energy by writing/drawing a response to the prompt in their science notebooks.

End of day 1

## 5 · NAVIGATE

3 min

**MATERIALS:** science notebook

**Turn and Talk.** Display **slide J**. Ask students to discuss the prompts with their neighbors. They may want to use ideas they wrote in their science notebooks at the end of the last class as they talk.

**Motivate quantification of matter and energy cycling in an ecosystem.** Ask a few students to share ideas from their conversation.

| Suggested prompt                                                                                            | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| How could the fire management techniques you read about change the flow of energy and matter in ecosystems? | <p>The cultural burns or prescribed burns reduce the amount of matter that can burn in a wildfire.</p> <p>The grazers reduce the amount of matter that can burn in a wildfire.</p> <p>The trees take carbon dioxide out of the atmosphere so it does not get hotter.</p>                                                                                                                                                                                                                                                                                     |
| What could we investigate to figure this out?                                                               | <p>Investigate different ecosystems where they have done these things.</p> <p>Get data about matter and energy in an ecosystem.</p>                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>ADDITIONAL GUIDANCE</b>                                                                                  | <p>These questions build on student understanding of concepts about ecology, which they figured out in <i>OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)</i>. These include carrying capacity (Lesson 5) and resilience (Lesson 8). If students did not experience this unit, draw on what students' know from prior grade bands such as MS LS2.B, which includes ideas about food webs, and then energy and matter flow between producers, consumers, and decomposers in ecosystems.</p> |

## 6 · RECALL COMPONENTS OF THE SERENGETI ECOSYSTEM

5 min

**MATERIALS:** *MakingSense Serengeti Fire*, whiteboard, dry erase markers

**Recall what we figured out about the Serengeti ecosystem (or other relevant choice).** Say, *Let's use an ecosystem we are familiar with to figure more of this out. Here is an ecosystem we looked at in the previous unit.* Display **slide K** or review another model for components, interactions, and mechanisms of an ecosystem that is familiar to students. Ask students to turn and talk about the flow of energy and matter in the Serengeti and what might increase risk of fire in the ecosystem. Use the prompts below as a guide.

| Suggested prompts                               | Sample student responses                                                                                            | Follow-up questions                                                                                                                                            |
|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| How do energy and matter flow in the Serengeti? | <p>From the grass to the wildebeest.</p> <p>From the wildebeest to the lions.</p> <p>From the Sun to the grass.</p> | <p>If there was a carbon sink in the Serengeti, where would it be?</p> <p>Where would the energy and matter from the carbon sink flow to in the Serengeti?</p> |
| What might increase the risk of fire?           | <p>Too much grass.</p> <p>Not enough rain.</p> <p>Not enough wildebeest.</p> <p>If it got hotter.</p>               | <p>What factors controlled how much grass there was in the Serengeti?</p> <p>What additional factors might be involved?</p>                                    |



### ALTERNATE ACTIVITY

The ecosystem presented for students to model is the Serengeti, which was the focus of *Serengeti Unit*. If your students are not familiar with the Serengeti or would find another ecosystem more relevant, modify the slides and *MakingSense Serengeti Fire* accordingly. Students should be familiar with producers, primary consumers, secondary consumers, and decomposers found in this ecosystem and be easily able to describe a basic food web or a few food chains in the system. Choose an ecosystem where fire occurs to facilitate transfer of ideas back to recovery from wildfires. One example is the American prairie, where there used to be many grazing animals (e.g., bison) and now there are frequent fires.

### ADDITIONAL GUIDANCE

If you are teaching these units out of order or did not use *Serengeti Unit*, draw on students' understanding of MS-LS2.B: *Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.* Students will likely already know the terms *herbivore* and *carnivore* from earlier grade bands and their lived experiences.

## 7 · MAKE SENSE OF ENERGY AND MATTER IN THE SERENGETI

10 min

**MATERIALS:** *Fire in Serengeti*, *MakingSense Serengeti Fire*

**Individual reading.** Say, *Like in many other places, it turns out that fire is an important part of the Serengeti ecosystem. Let's investigate that more.* Display **slide L** and distribute *Fire in Serengeti* to each student. Give them time to read and mark up the text using whatever reading strategy is in place in your classroom.

**Small-group sensemaking.** Organize students into small groups of 3-5 students. Distribute *MakingSense Serengeti Fire* to each student. Ask students to work together to answer the questions on part one of the handout. Circulate around the room as students work to make sure they identify how each fire management technique works affects the flow of energy and matter. The images from the handout can be found on **slides M-O**.

## 8 · USE A MATHEMATICAL REPRESENTATIONS OF ENERGY AND MATTER IN THE SERENGETI

12 min

**MATERIALS:** science notebook, *Fire in Serengeti*, *MakingSense Serengeti Fire*



**Represent energy and matter flows with fire management techniques.**

Display **slide P**. Ask each group of students to work together to complete parts two and three on *MakingSense Serengeti Fire*. The image from the handout can be found on **slide Q**.

## ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** Listen for the following as students build and revise their models in small groups and when they turn in one copy of *MakingSense Serengeti Fire*:

- Energy from the Sun is used by plants to make plant biomass. (DCI: LS2.B.2; CCC: 5.3)
- Plants use some of the sugar they make from photosynthesis to carry out cellular respiration. (DCI: LS2.B.2; CCC: 5.3)
- When the grazers eat the plants, they use some of the energy/matter to do cellular respiration, some to make more biomass, and they get rid of some of it as waste. (DCI: LS2.B.2; CCC: 5.3)
- Decomposers break down the waste, use the energy for cellular respiration, make more biomass, and get rid of waste, also returning nutrients to the soil. (DCI: LS2.B.2; CCC: 5.3)
- More biomass exists in producers than consumers. (SEP: 5.2; DCI: LS2.B.2; CCC: 5.3)
- Only a small fraction of energy and matter is transferred to consumers. (SEP: 5.2; DCI: LS2.B.2; CCC: 5.3)
- Large amounts of energy and matter are used for cellular respiration to grow, move, for other life functions, or are lost as heat and are not available for consumption at the next level of the food web. (SEP: 5.2; DCI: LS2.B.2; CCC: 5.3)
- Matter is rearranged into different forms at each level of the food web. (DCI: LS2.B.2; CCC: 5.3)

**What to do:** As students create, share, and revise their models, use the following prompts. When you review *MakingSense Serengeti Fire*, provide comments to help students consider the following:

- Ask what form the carbon is in at each level.
- Ask how the energy is transformed for each interaction.
- Ask students to trace the carbon as it loops through the system.
- Challenge students to mathematically determine the cumulative proportion of energy from producers that makes it to the carnivores.
- Ask what would happen if herbivores ate all of the producers, or carnivores ate all of the herbivores.
- Ask how producers take in different forms of matter (carbon, water, nutrients).
- Ask if herbivores eat the entire plant.
- Ask students to estimate what proportion of food an animal eats passes through its body daily once it is fully grown.
- Ask how the matter and energy are still used even if they do not become part of the body.

**Building toward 10.B** Use mathematical representations to support claims about the cycling of matter and flow of energy among organisms in an ecosystem. (SEP: 5.2; DCI: LS2.B.2, CCC: 5.3)

## 9 · BUILDING UNDERSTANDINGS: CONNECT MATTER AND ENERGY CYCLING TO FIRE MANAGEMENT

10 min

**MATERIALS:** science notebook, *Fire in Serengeti*, *MakingSense Serengeti Fire*

**Connect the model to fire management techniques.** Display slide R and use the prompts below as a guide to support student thinking.\*

### Suggested prompt

*How are the fire management techniques related to the flow of energy and matter in the Serengeti?*

### Sample student response

They all try to reduce either the amount of fuel or the amount of heat available.

### \* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful kind of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and

| Suggested prompt                                               | Sample student response                                                                                                                                                                             |
|----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>How does grazing help prevent fire?</i>                     | The matter and energy that move from producers into the herbivore consumers is no longer available to burn.<br><br>Some of the nutrients also get returned to the soil, so the system is healthier. |
| <i>How do prescribed and cultural burns help prevent fire?</i> | It removes matter and energy from the carbon sink that could burn.<br><br>It also puts some carbon dioxide into the atmosphere.                                                                     |
| <i>How does planting trees help prevent fire?</i>              | It takes some of the carbon dioxide out of the atmosphere so it is not as hot.                                                                                                                      |

claims and to push them to support their claims with evidence. Students can disagree with each other, and the class does not need to reach consensus on all ideas shared. Areas of disagreement can motivate future investigations. Helpful prompts during these kinds of discussions include:

- What can we conclude?
- How did you arrive at that conclusion?
- What's your evidence?
- Does any group have evidence to support A's claim?
- What data do we have that challenges B's claim?

## 10 · NAVIGATE: UPDATE PROGRESS TRACKER

5 min

MATERIALS: *Fires Progress Tracker*

**Update Progress Tracker.** Display slide S. Suggest that students update *Fires Progress Tracker* with what they figured out about the lesson question. They should also record wonderings they have about actually implementing these techniques successfully. One possible representation of a completed Progress Tracker is shown below.

|                                                                                           | What we figured out (WWFO)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | How does WWFO help us make progress on our Driving Question about zombie fires?                                                                 | How does WWFO connect to me or my community or have a larger-scale impact?                                                                                                                                                                                                                                                                                                                  | What questions do I have now?                                                                                                                                   |
|-------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Lesson 10:</b><br><b>How can we help manage the matter and energy in fire systems?</b> | <p>-We figure out that successful fire management disrupts the positive feedback loop we saw in Lesson 9.</p> <p>-Prescribed and cultural burning reduces the amount of fuel available to burn, restoring grazers to ecosystems reduces the amount of fuel available to burn, and planting trees in areas that have been deforested restores the matter and energy to the food web.</p> <p>-Only a small fraction of matter and energy move from producers to consumers, but it is enough to reduce big wildfires if done correctly.</p> | Fire management helps reduce the amount of carbon sink available to burn in wildfires and could reduce temperatures that make fire risk higher. | <p>I was worried going into this lesson that there was little we could do to stop wildfire, but after learning about these different techniques, I am feeling more hopeful.</p> <p>I hope that my own community does more to help educate people on Indigenous knowledge systems and how we can work together with people who have different perspectives to make fire management plans</p> | <p>-Can we restore parts of other ecosystems using these management techniques?</p> <p>-What does it take to actually use these strategies in other places?</p> |

## End of day 2

## MATERIALS: None

**Review beneficial uses of fire.** Display slide T. Ask students to turn and talk about the prompts on the slide. Encourage them to look back at their case studies and science notebook for ideas. After a minute or two, bring the class together and ask students to share an idea and then call on someone else to share. Listen for answers such as: preventing large wildfires, adding nutrients to the soil, burning off dead material that shades other plants, preventing trees from growing into a prairie, providing animal habitat, etc.

## 12 · DISCUSS THE VALUE OF SHARING KNOWLEDGE FROM MULTIPLE CULTURES FOR MANAGING FIRE

15 min

## MATERIALS: None

**Discuss how people figure out the benefits of fire.** Display slide U. Ask, *How do people figure out these benefits of fire?* Listen for students to mention:

- Scientific studies
- Observation
- Oral tradition/Indigenous knowledge

**Acknowledge the Indigenous past, present, and future of case study locations.** Display slide V. Say, *What we understand about the benefits of intentionally burning ecosystems comes from many different knowledge holders. As we read about in Lesson 7 and this lesson, many Indigenous groups have been using fires in beneficial ways for millennia. It is important to note that the reason these Indigenous knowledge systems that have kept ecosystems in balance have fallen out of practice is because the lands we live on were taken from them. Specifically for our case studies, the Menominee, Ojibwe, Potawatomi, and Ho-Chunk peoples are some of the original inhabitants of what we now call Wisconsin, and Washoe, Northern Paiute, Southern Paiute, and Western Shoshone are some of the original inhabitants of what we now call Nevada. We also acknowledge any tribes not stated here and any tribes we do not know about due to colonization. Research the history of the land your school sits on using the information at: <https://native-land.ca/>*

**ADDITIONAL GUIDANCE**

While acknowledging the history of the land is good practice, it is only a first step in working to address the damage done to communities by erasing traditional knowledge. Words should be accompanied by conversation and additional action. Learn more here: <https://nativegov.org/news/a-guide-to-indigenous-land-acknowledgment/>.

**Watch a video about cultural burning collaboration.** Say, *I overheard some of you say that you wished you could have watched the video that the group reading about cultural burning saw, so let's all take time to watch it together. As you do, think about how knowledge is shared between groups.* Display slide W and watch <https://youtu.be/kKmRf6HEOFI>. After students watch the video, ask them to turn and talk about the prompts on slide X. After a minute, ask a few groups to share their thoughts.

| Suggested prompt                                                                                          | Sample student response                                                                                    |
|-----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Whose perspectives were taken into account when the decision was made to do this form of fire management? | The Dja Dja Wurrung shared their knowledge with members of the forest fire management service in Victoria. |

| Suggested prompt                                                             | Sample student response                                                                                                                                                                                                                                 |
|------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| What are the benefits of management with this type of collaboration?         | <p>Everyone gains Indigenous knowledge.</p> <p>It respects the knowledge of the Dja Dja Wurrung and its people.</p> <p>There are more people and there is more money available to do the work.</p> <p>It could prevent large wildfires.</p>             |
| What are the challenges of doing management with this type of collaboration? | <p>The Dja Dja Wurrung might not trust the government.</p> <p>Some people may not believe in the methods the Dja Dja Wurrung are doing.</p> <p>Some people do not believe that cultural practices should be part of the science of fire management.</p> |

#### ADDITIONAL GUIDANCE

The concepts of power and historicity, addressed in Lesson 7, resurface here. The video references that the land has not seen fire for 170 years. Students should remember from *Victoria Carbon Sink (Australia)* that this is because of the massacres of Aboriginal people that took place when the British colonized the area. This video shows how some rebalancing of power is occurring through this process. This respect for the knowledge of the Dja Dja Wurrung is part of a healing process, but students may recognize that this will not solve the long-term imbalance completely.

**Revisit nature-culture relationships in socio-ecological systems.** Display slide Y. Ask students to review these two perspectives that they discussed in *Serengeti Unit*. If this is the first time they are seeing this image, walk through the figure depicting two possible relationships between humans and the environment. Explain how people can sometimes have the traditionally Western perspective that humans dominate all other living creatures or have a perspective about how we coexist and depend on relationships with all other living creatures. These contrasting perspectives of dominance or reciprocity influence how people think about the natural world and, in turn, do fire management.

## ADDITIONAL GUIDANCE

The diagram on **slide Y** comes from the Learning in Places Nature-Culture Relationships Framework cited below. It describes two main models of nature-culture relations: “1) humans ‘**apart from**’ the natural world, or what we call nature-culture divides; and 2) humans are ‘**a part of**’ the natural world, or what we call **nature-culture complementarities**. In nature-culture divides, humans are generally positioned as apart from or on top of the natural world.” This puts people in a position of power to control all other parts of the natural world. “The . . . apart from’ models also tend to reflect powered social systems particularly with respect to gender and race.”

“In nature-culture complementarities, humans are generally positioned as a part of the natural world. These ‘a part of’ relationships tend to position humans as one of many actors in the natural world and often reflect deferential or reciprocally powered relationships and tend to extend dignity and rights to more than human life.”

*Learning in Places Collaborative (2022). Nature-Culture Relationships Framework.* Bothell, Seattle, WA & Evanston, IL: Learning in Places. P. 1. Read more about this at: [http://learninginplaces.org/wp-content/uploads/2021/10/framework\\_Nature\\_Culture\\_Relations\\_rev101321.pdf](http://learninginplaces.org/wp-content/uploads/2021/10/framework_Nature_Culture_Relations_rev101321.pdf)

## 13 · CONNECT TO RELATED PHENOMENA

20 min

**MATERIALS:** *Fire Risk Home-Learning*, internet-connected device, chart of wonderings from day 1, Related Phenomena poster from Lesson 1, DQB, chart paper markers

**Share wonderings from other case studies and related phenomena.** Say, *While we are talking about challenges of doing collaborative cultural burns like the one in Victoria, let's share more about the wonderings we had from the other case studies and questions they sparked about related phenomena.* Display **slide Z**. Make sure the Related Phenomena poster from Lesson 1 is visible. Also, repost the chart of wonderings made on day 1 and add to it. Encourage students to look back at the case studies they read along with *Fires Progress Tracker* to find ideas to add to the discussion.

### Suggested prompt

*What additional wonderings did you have from the management case studies?*

*What other related phenomena does this make you wonder about?*

### Sample student response

How much does it cost to plant all of those trees?

How long does it take to restore balance to an ecosystem?

How do you make sure cattle eat the right amount of grass to prevent wildfires?

Why are they using cattle instead of wild animals to graze?

How do they make sure the prescribed burns do not get out of control?

Is this the same idea as when they had goats clear the land near our house?

Would prescribed burning work in a forest/grassland here?

Do they do prescribed burns in the Serengeti?

After hearing the new questions students add, say something like, *It sounds like we are wondering a lot about more than just zombie fires* (walk over to the Related Phenomena poster) *and if there is something we can do to stop or reduce fires. Can someone suggest a new Driving Question that includes these ideas?* Listen for students to suggest questions like:

- *How do we design solutions to manage the impacts of fires?*
- *How can we help our communities?*
- *How can we help places, lands, and water we care about?*

When a potential, new Driving Question arises, repeat it aloud, and ask, *Do you think that by answering this question, we will have answers to most of the remaining questions on our Driving Question Board?* Look for agreement using a show of hands and then write the chosen question at the top of the DQB with a chart paper marker.

Say, *It sounds like we have questions about some related phenomena and are thinking about ways to use these management techniques in other communities we care about. I found a tool that can help us investigate some of the other communities we are interested in so we can start to think about ways to lower the risk of wildfire in those communities.*

**Investigate fire risk in the community near your school.** Display slide AA and distribute *Fire Risk Home-Learning* to each student. Make sure pairs of students have access to an internet-connected device. Demonstrate how to do steps 1-4 on *Fire Risk Home-Learning* at the front of the class, using the area around your school. Then provide time for students to investigate a community they are concerned about as they complete steps 1-4 with their partners.

 **Share noticings.** After students have had about 10 minutes to research on their own, bring the class together to share some of their noticings. Display slide BB. Use the suggested prompts below to promote sharing \*:

| Suggested prompts                                                   | Sample student responses                                                                                                                        | Follow-up questions                                                    |
|---------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| <i>What fuels are at risk in the community?</i>                     | Homes<br>Forests<br>Grassland                                                                                                                   | <i>Can you say more about that?</i><br><i>Can you give an example?</i> |
| <i>What groups of people are vulnerable?</i>                        | People over age 65.<br>Many people of color.<br>Many people live in poverty.                                                                    | <i>Who can add onto the idea that _____ is building?</i>               |
| <i>How does the risk in your community compare to other places?</i> | We have a low/high risk compared to other places in our county/state/nation.<br>We have more children living in our community than community x. | <i>How did you determine this?</i>                                     |



| Suggested prompts                                                               | Sample student responses                                                                                                                                                                                                                                               | Follow-up questions                                                                                                                             |
|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>How does that risk make fire management more challenging?</i>                | <p>We have a large number of people with limited English, so if we want to teach people about preventing a wildfire, we need to translate it.</p> <p>If there are many vulnerable homes, we might not be able to do prescribed burns because the homes could burn.</p> | <p><i>What could be done to reduce that risk?</i></p> <p><i>What could be done to help that group of people and lessen the risk?</i></p>        |
| <i>What techniques might work to reduce the risk of fire in your community?</i> | <p>Prescribed burning.</p> <p>Clearing brush away from homes.</p> <p>Planning evacuation routes and distributing them in multiple languages.</p>                                                                                                                       | <p><i>How does that reduce the size of the carbon sink?</i></p> <p><i>How does that change the flow of matter and energy in the system?</i></p> |

## ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** The need for a plan in their community of concern that (SEP: 1.8):

- Protects fuel sources like homes and small parks from ignition. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)
- Include systems that protect vulnerable groups from harm. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)
- Includes perspectives and input from multiple groups to address all parts of the system that are likely to burn. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)

**What to do:** As students discuss the community risk and possible plan ask these questions:

- Whose perspectives are needed before fire management decisions are made?
- How does this make the matter and energy in this community less likely to burn?
- What parts of the system need to be considered for the solution to work well?

**Building toward 10.C** Define the need for a plan to reduce the risk of wildfire in a community of concern and the social and environmental components that make the system likely to burn. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)

## 14 · NAVIGATE: INTRODUCE HOME LEARNING

5 min

**MATERIALS:** *Fire Risk Home-Learning*



**Introduce home learning activity.** Say, *We have started to investigate ways to protect the communities we care about from the risk of wildfire. Just as we saw multiple groups sharing their knowledge in the video we watched today, let's try to gather ideas from multiple knowledge holders in our own communities.* Display slide CC. Review the questions on the second part of *Fire Risk Home-Learning* with students. Brainstorm trusted adults or community members students may want to speak with about these questions. They may want to show them the wildfire risk website they investigated, but the discussions could also occur by sharing the information they recorded on the first part of the assignment during class. Explain that they will share this information in the next class. \*

### \* ATTENDING TO EQUITY

Framing students' families and communities as legitimate sources of knowledge can serve multiple purposes. It can 1) help students feel like they belong in the science classroom by situating their family/community knowledge as productive for science, 2) engage students' families in conversations about what is happening in the classroom, and 3)

## Additional Lesson 10 Teacher Guidance

**SUPPORTING  
STUDENTS IN  
MAKING  
CONNECTIONS IN  
ELA**

**CCSS.ELA-LITERACY.RST.9-10.2** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

As students read the case studies, they summarize the information presented in the text to convey the central ideas of the processes to their jigsaw groups.

**SUPPORTING  
STUDENTS IN  
MAKING  
CONNECTIONS IN  
MATH**

**MP.4.** Model with Mathematics

Students create a model showing the estimated proportion of matter and energy cycling through a food web. Students decide on the way to represent proportion.

help students make connections between the science classroom and their everyday lives.



# LESSON 11: What decisions can we make to help manage fire in communities we care about?

## PREVIOUS LESSON

We investigated four case studies of successful fire management. We figured out how prescribed burning, cultural burning, restoring grazer populations, and replanting forests help manage the amount of available carbon and energy that could burn in wildfires. We developed a mathematical representation to explain how these techniques could alter the flow of energy and matter in these ecosystems. We investigated fire risk in our own community and began to define a plan for reducing that risk.

## THIS LESSON

### PUTTING PIECES TOGETHER

3 days



US Forest Service

We design fire management systems for places, lands, and waters in our community. We break down fire management criteria, identify constraints, and design systems. We close the Driving Question Board and revisit our Progress Trackers.

## NEXT LESSON

We will complete a Transfer Task about eutrophication in marine ecosystems to demonstrate how what we figured out throughout the unit about the flow of energy and matter applies to other systems.

## BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



## WHAT STUDENTS WILL DO

**11.A** Design and refine simpler criteria for a fire management solution with the desired effect of reducing risk and balancing matter and energy in the system. (SEP: 6.5; DCI: ETS1.C; CCC: 2.3)

**11.B** Design and refine a solution for fire management (based on simpler criteria) to reduce risk and balance matter and energy in the system. (SEP: 6.5; DCI: ETS1.C & LS1.C3; CCC: 2.3)

**11.C** Communicate scientific and technical information or ideas in multiple formats to prioritize criteria and make trade-offs in the fire management system designed to change the flow of matter and energy. (SEP: 8.5; DCI: ETS1.C; CCC: 4.1)

## WHAT STUDENTS WILL FIGURE OUT

- Criteria need to be broken down into simpler ones to manage fire to see who will be impacted (human and nonhuman) by our decisions.
- Making decisions involves and impacts people at many levels in the systems we care about.
- The places, lands, and waters we care about are complex, and decisions about prioritizing specific criteria over others (trade-offs) may be needed.

## Lesson 11 • Learning Plan Snapshot

| Part                | Duration |                                                                                     | Summary                                                                                                                                                                                                  | Slide | Materials                                                                                                                                                           |
|---------------------|----------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                   | 5 min    |                                                                                     | <b>NAVIGATE</b><br>Revisit ideas about personal fire risk and the home learning from Lesson 10.                                                                                                          | A-B   | <i>Fire Risk Home-Learning</i> , whiteboard and dry erase markers or chart paper and chart paper markers                                                            |
| 2                   | 5 min    |                                                                                     | <b>INTRODUCE CRITERIA AND CONSTRAINTS</b><br>Facilitate a discussion to bring out current understandings of criteria and constraints.                                                                    | C-D   |                                                                                                                                                                     |
| 3                   | 7 min    |                                                                                     | <b>BRAINSTORM CRITERIA AND CONSTRAINTS</b><br>Facilitate a whole-class discussion about criteria, constraints, and potential solutions.                                                                  | E-G   | <i>Engineering Design Organizer</i> , Lesson 10 Chart of Wonderings, whiteboard and dry erase markers or chart paper and chart paper markers, class consensus model |
| 4                   | 9 min    |                                                                                     | <b>RESEARCH BACKGROUND INFORMATION</b><br>Support students in researching background information about their local community to develop a fire management solution.                                      | H     | internet-connected device, map of community, <i>Prioritizing Criteria/Constraints</i>                                                                               |
| 5                   | 7 min    |                                                                                     | <b>REVISE CRITERIA AND CONSTRAINTS FOR THEIR COMMUNITY</b><br>Revise the criteria and constraints for their community based on additional information gathered from research.                            | I     | <i>Prioritizing Criteria/Constraints</i> , <i>Fire Solutions Sample</i>                                                                                             |
| 6                   | 10 min   |    | <b>PRIORITIZE CRITERIA</b><br>Use <i>Prioritizing Criteria/Constraints</i> to prioritize criteria and break them down into simpler criteria to begin building solutions.                                 | J-K   | <i>Prioritizing Criteria/Constraints</i> , computer/tablet with access to the internet                                                                              |
| 7                   | 2 min    |                                                                                     | <b>NAVIGATE</b><br>Use home learning to propose criteria with community members.                                                                                                                         | L     | <i>Prioritizing Criteria/Constraints</i>                                                                                                                            |
| <i>End of day 1</i> |          |                                                                                     |                                                                                                                                                                                                          |       |                                                                                                                                                                     |
| 8                   | 5 min    |                                                                                     | <b>NAVIGATE: SHARE HOME LEARNING</b><br>Share home learning to integrate community knowledge.                                                                                                            | M     | <i>Prioritizing Criteria/Constraints</i> , Class list from day 1                                                                                                    |
| 9                   | 7 min    |                                                                                     | <b>INTRODUCE TRADE-OFFS</b><br>Facilitate a discussion of possible solutions and constraints to implementing them. Discuss trade-offs.                                                                   | N-O   |                                                                                                                                                                     |
| 10                  | 10 min   |  | <b>DESIGN A FIRE MANAGEMENT SYSTEM</b><br>Brainstorm ways that solutions learned from community conversations can be connected to create actions for fire management systems.                            | P     | <i>Prioritizing Criteria/Constraints</i> , <i>Designing Fire Solutions</i>                                                                                          |
| 11                  | 20 min   |                                                                                     | <b>CREATE FIRE MANAGEMENT SYSTEM PRODUCTS</b><br>Support students in creating a product of their fire management system to inspire community members to manage the energy and matter of their ecosystem. | Q-R   | <i>Designing Fire Solutions</i>                                                                                                                                     |

| Part                | Duration |                                                                                   | Summary                                                                                                                                            | Slide | Materials                                                                                    |
|---------------------|----------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|-------|----------------------------------------------------------------------------------------------|
| 12                  | 3 min    |                                                                                   | <b>NAVIGATE: SOCIAL EMOTIONAL CHECK-IN</b><br>Create space for a social-emotional check-in.                                                        | S     |                                                                                              |
| <i>End of day 2</i> |          |                                                                                   |                                                                                                                                                    |       |                                                                                              |
| 13                  | 5 min    |                                                                                   | <b>NAVIGATE: PREPARE TO PRESENT FIRE MANAGEMENT SYSTEM PRODUCTS</b><br>Facilitate students in presenting fire management system products to peers. | T-U   | <i>Peer Feedback Guidelines, Designing Fire Solutions</i> , fire management solution product |
| 14                  | 10 min   |  | <b>COMMUNICATE FIRE MANAGEMENT SYSTEM PRODUCTS</b><br>Arrange students into mixed groups to share their products.                                  | V     | 3x3 sticky notes, <i>Designing Fire Solutions</i> , fire management solution product         |
| 15                  | 5 min    |                                                                                   | <b>SELF-ASSESS PEER FEEDBACK ON FIRE MANAGEMENT</b><br>Self-assess peer feedback on fire management systems.                                       | W     | <i>Feedback Self-Assessment</i>                                                              |
| 16                  | 20 min   |                                                                                   | <b>CLOSE THE DRIVING QUESTION BOARD</b><br>Revisit the DQB with the class to take stock of all of the questions we have now answered.              | X-Y   | <i>DQB Questions</i> , Driving Question Board                                                |
| 17                  | 5 min    |                                                                                   | <b>NAVIGATE</b><br>Direct students to return to their Progress Trackers to think about what we have figured out in this lesson unit.               | Z- AA | <i>Fires Progress Tracker</i>                                                                |
| <i>End of day 3</i> |          |                                                                                   |                                                                                                                                                    |       |                                                                                              |

## Lesson 11 • Materials List

|                  | per student                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | per group                                                                                                                                                                          | per class                                                                                                                                                                                                                                                                                                 |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson materials | <ul style="list-style-type: none"><li>• <i>Fire Risk Home-Learning</i></li><li>• science notebook</li><li>• <i>Engineering Design Organizer</i></li><li>• internet-connected device</li><li>• map of community</li><li>• <i>Prioritizing Criteria/Constraints</i></li><li>• <i>Designing Fire Solutions</i></li><li>• <i>Peer Feedback Guidelines</i></li><li>• 3x3 sticky notes</li><li>• <i>Feedback Self-Assessment</i></li><li>• <i>DQB Questions</i></li><li>• <i>Fires Progress Tracker</i></li></ul> | <ul style="list-style-type: none"><li>• computer/tablet with access to the internet</li><li>• <i>Designing Fire Solutions</i></li><li>• fire management solution product</li></ul> | <ul style="list-style-type: none"><li>• whiteboard and dry erase markers or chart paper and chart paper markers</li><li>• Lesson 10 Chart of Wonderings</li><li>• class consensus model</li><li>• <i>Fire Solutions Sample</i></li><li>• Class list from day 1</li><li>• Driving Question Board</li></ul> |

### Materials preparation (20 minutes)

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

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

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

Gather chart paper and chart paper markers or equivalent (if needed).

You should have already created the handout *DQB Questions* for your class. If a significant number of student questions have been added to the DQB since then, create an updated version with those new questions and prepare to distribute that to students in addition to their original copy.

Day 1:

- Gather an internet-connected device for each student.
- Consider creating a list of useful community websites and search terms in advance to support student research to answer questions on *Prioritizing Criteria/Constraints* Part 1.
- Print out a map of your community to provide each student with a tool they can write on as they work.

## Lesson 11 • Where We Are Going and NOT Going

### Where We Are Going

This lesson aims to help students see themselves as agents of change and caretakers of different communities' places, lands, and waters. Students will use much of what they figured out in the unit to develop a fire management solution as part of an engineering design task.

As they do this, they build an understanding of elements of engineering, technology, and the application of science (ETS). In *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* students previously used elements of this domain as they focused on criteria and constraints different interest holders prioritize in evaluating road proposals in Lesson 9. Here, students focus on criteria and trade-offs *Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.* (HS-ETS1.C.1) building on their middle school understanding of criteria from (MS-ETS1.B) *There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.*

Students use the science and engineering practice *designing solutions*. In *Serengeti Unit*, students used this element to evaluate solutions for a proposed road in the Serengeti. Here, they use the element in a new way to design their own fire management systems. Students also use the practice *obtaining, evaluating, and communicating information* to communicate information in a similar way as they did in *Serengeti Unit*.

Students develop the use of the crosscutting concepts *cause and effect* and *systems and system models* in a new way as they design systems that cause a desired effect. They build on their middle school use of *systems and system models*, where they considered interaction systems and subsystems.

Students co-construct a definition for *trade-offs*, which they should add to their Personal Glossaries. If the terms *criteria* and *constraints* are new for your students, add them to their Personal Glossaries as well. Students will reenounter *interest holder* and can revise their definition based on the new ideas from this lesson. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

### Where We Are NOT Going

The DCI, ETS1.C.1, is further addressed in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, an entire unit focused on design and engineering.



# LEARNING PLAN for LESSON 11

## 1 · NAVIGATE

5 min

**MATERIALS:** *Fire Risk Home-Learning*, whiteboard and dry erase markers or chart paper and chart paper markers

**Turn and talk to share home learning.** Display **slide A**. Ask students to share with their shoulder partners what they heard from their community members as they completed *Fire Risk Home-Learning* from Lesson 10. Call on volunteers to share and record their ideas on a whiteboard or chart paper.

| Suggested prompt                                                                                                                      | Sample student response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What concerns you and others in your community most about the fire risk? Consider human and nonhuman members of the community.</i> | <p>I am worried about losing my home.</p> <p>I am worried about what would happen to the animals in the woods around my home.</p> <p>I am worried about my grandmother not being able to get out of her house.</p> <p>The fire risk in our city is low, but there are many forests nearby, and we could be affected by smoke.</p> <p>There are many vulnerable populations in our community that cannot get away from a fire even if the risk of fire is low.</p>                                                               |
| <i>Who are the knowledge holders we should consult in this community when planning to reduce fire risk?</i>                           | <p>The fire department, police, and the mayor.</p> <p>I know someone who does prescribed burns.</p> <p>People who have lived in the area for a long time.</p>                                                                                                                                                                                                                                                                                                                                                                   |
| <i>What should we ask or tell the people in power who currently make decisions about managing fire risk?</i>                          | <p>What is the evacuation plan for helping older people if there is a fire?</p> <p>Do we need a fire break around this building?</p> <p>We should be using renewable energy sources so we can reduce CO<sub>2</sub> emissions.</p> <p>We should consider letting goats graze in the woods.</p> <p>We are recovering from a fire. We should plant more trees.</p> <p>We should find people who have done cultural burning to hear their ideas.</p> <p>Think about bringing bison back to eat the tall grass that could burn.</p> |

**Update Personal Glossaries.** Display **slide B**. Say, *You mentioned many different people who would be impacted or could help with fire management in your community.* Remind students about the word *interest holder* that they encountered in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. Come to a consensus on additional language to add to their definition of interest holder as they think about these new ideas of fire management and managing the flow of matter and energy.

**ADDITIONAL GUIDANCE**

If students have not encountered the definition for *interest holder*, take time for students to add it to their Personal Glossary. Interest holders are individuals or groups with varying views and interests in the outcome of a particular project or event. In this lesson, we are using the term *interest holders* instead of *stakeholders*, which has roots in colonialism and may be problematic for some individuals or groups. Feel free to use terminology that you and your students are comfortable with. Examples include *rights holders* or *interested parties*. Pause to give students a moment to enter or update the term in their Personal Glossaries as a word or definition we encounter.

2 · INTRODUCE CRITERIA AND CONSTRAINTS

5 min

MATERIALS: science notebook

**Relate home learning to fire management solutions.** Display **slide C**. Engage students in a short discussion to extend their thinking around the home learning to relate it to the ideas of criteria and constraints. Say, *Our home learning helped us think about relevant actions that our communities can take to prevent fires. Many communities organize those actions into a fire management system.*

| Suggested prompt                                                                           | Sample student response                                                                                                                                                                                                                                  |
|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Why would we need a fire management system?                                                | To prevent fires or make them less dangerous.                                                                                                                                                                                                            |
| If we designed a fire management system what would we want it to do?                       | Protect people, families, homes, pets, wild animals, important buildings.<br><br>Make sure that fire does not spread.<br><br>Make sure we had a plan in place to stop the fire once it started.<br><br>Help vulnerable people escape if there is a fire. |
| What are some of the problems that could get in the way of trying to implement the system? | If there were different ideas/disagreement about which homes and buildings should be saved.<br><br>Some pets are easier to rescue than others.<br><br>There could be more people and animals to save than resources to do so.                            |
| If we developed a system to protect our community, how could we judge our success?         | We would have minimal loss of life and structures.<br><br>We would be able to evacuate as many humans and nonhumans from danger.                                                                                                                         |

**Introduce criteria and constraints.** Display **slide D**. As students think of the goals for a fire management system and the problems they might encounter in implementing it, remind them that these ideas are called *criteria* and *constraints*. If necessary, revisit the definitions of these terms.

#### ADDITIONAL GUIDANCE

Students should be familiar with the terms *criteria* and *constraints* from *Serengeti Unit*, where they discussed criteria and constraints in the context of various interest holders and road proposals in the Serengeti. If students need additional support, their previous definition for *criteria* may be similar to *the requirements our design needs to meet to be considered successful*, and their definition for *constraint* may be similar to *the social, economic, and potentially governmental challenges that they might have to contend with*.

### 3 · BRAINSTORM CRITERIA AND CONSTRAINTS

7 min

**MATERIALS:** *Engineering Design Organizer*, science notebook, Lesson 10 Chart of Wonderings, whiteboard and dry erase markers or chart paper and chart paper markers, class consensus model

**Brainstorm possible criteria and constraints.** Display **slide E**. Distribute *Engineering Design Organizer*. Explain to students that they will use their home learning, the Lesson 10 case studies, and their class consensus model (**slide F**) to brainstorm ideas for criteria and constraints for fire management in *Engineering Design Organizer*. Say, *Let's complete the first row together*. Share ideas from your own community to explain how to complete the table. Then give students a few minutes to fill in the table on their own using ideas from the home learning.

|                        | Criteria                                        | Constraints                                                                                                                   |
|------------------------|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Lesson 10 Case Studies | Reduce the amount of fuel available for a fire. | Some people might not want to set controlled burns so close to neighborhoods.<br><br>There are no cattle grazing in the area. |
| Home Learning          | Make the homes in my community safe from fire.  | The terrain is difficult to get around to fight a fire if one was to break out.                                               |

**Share with a partner.** Display **slide G**. Ask students to share ideas from their handouts with their elbow partners. Say, *As you listen to your partner's ideas, look to see what ideas you have in common and what new ideas your partner has*. Give them a few minutes to share their ideas as you circulate to listen in.

**Whole-class discussion.** Make a two-column chart on the whiteboard or chart paper that matches *Engineering Design Organizer* with columns for criteria and constraints. Call on pairs of students to share their criteria and constraints and compile a class list.

#### ALTERNATE ACTIVITY

**Extension:** If your students are interested in an additional historical example of a fire management system, investigate *Optional: Smokey Bear Campaign* to learn about the Smokey Bear campaign. Add another row of criteria and constraints that they think of on *Engineering Design Organizer* after hearing about this fire management solution. See *Smokey Bear Optional* for support.

### 4 · RESEARCH BACKGROUND INFORMATION

9 min

**MATERIALS:** internet-connected device, map of community, *Prioritizing Criteria/Constraints*

**Use *Prioritizing Criteria/Constraints* to research the local community.** Say, *You all had some great ideas about what criteria and constraints you might need to consider in a fire management system. Let's focus on our own community again and the species, places, lands, and waters found here. We should also consider who holds the power to make and enact decisions as we design ways to protect the living and nonliving components of these systems. Let's think about what else we need to understand about our community to design an effective fire management system.*

Discuss the list of items to research on *Prioritizing Criteria/Constraints* along with productive search terms or websites to visit to provide accurate information about your community. Display **slide H**. Provide each student with an internet-connected device and a map of the community. Organize them into groups of 3-5 and ask them to divide up the research topics. Complete questions 1-3 on part 1 of *Prioritizing Criteria/Constraints*.

#### **ADDITIONAL GUIDANCE**

City, town, or county websites often offer information on demographics, parks and recreational areas, programs for vulnerable individuals, and names of elected officials. Local maps are useful for finding parks, bodies of water, and other important locations that need protection. Possible search terms include:

- *City of \_\_\_\_ statistics*
- *Map of \_\_\_\_*
- *(Community name) native plants/animals*
- *(Community name) parks*
- *Community of \_\_\_\_ elected officials*
- *Rivers/lakes of \_\_\_\_ community*
- *Fire department, (community name)*

If students live in a large city, groups may choose to focus on specific neighborhoods or parts of the city of importance to them. If they choose to do a different part of the community or a completely different location from the rest of the class, ensure that they use the same checklist to identify information about the same components of the community. Students may need to draw a map of this community if the area is not included in the map you provided. Note that the lesson proceeds with the assumption that students are working on the same community.

## **5 · REVISE CRITERIA AND CONSTRAINTS FOR THEIR COMMUNITY**

7 min

**MATERIALS:** *Prioritizing Criteria/Constraints*, *Fire Solutions Sample*

**Revise criteria and constraints based on new ideas.** Say, *Now that we have more specific information about our community, how can we use this information to revise our criteria and constraints?* Display **slide I** and provide time for groups to complete question 4 on *Prioritizing Criteria/Constraints*.

**Share criteria and constraints.** Bring the class together and revise the class list of criteria and constraints for your community as needed based on the research, collecting ideas from all groups. See *Fire Solutions Sample* for sample answers. Once you have all of the ideas, say, *This is a huge list; are these all equally important? Can we do all of these things? How do we decide what to include?*

## **6 · PRIORITIZE CRITERIA**

10 min

**MATERIALS:** science notebook, *Prioritizing Criteria/Constraints*, computer/tablet with access to the internet

**Stop and Jot.** Display **slide J**. Say, *Review your revised criteria. Which two are most important to you and why? What effect will your chosen criteria cause in the flow of matter and energy in the system? How do your choices represent your values and the trade-offs you are willing to make? Provide*

time for students to respond to these questions individually in their science notebooks.

 **Prioritize criteria in groups.** Display *slide K*. Explain that each student will share their top two criteria and reasons for choosing them with their group. The group will then come to an agreement on one criterion they want to focus on together. They will then complete question 1 on Part 2 of *Prioritizing Criteria/Constraints*. Talk through an example, for how to break down criteria into simpler, more manageable criteria. Two examples are shown in *Fire Solutions Sample*.

## ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** See *Progress Tracker Key* for student ideas on example of *Prioritizing Criteria/Constraints*.

- Students articulate what **effects** their **simple criteria** for a proposed **fire management solution** will have for changing the **flow of energy and matter** of their chosen **system**. (SEP: 6.5; DCI: ETS1.C, LS1.C3; CCC: 2.3)
- Students describe how their **simple criteria** for their proposed **fire management solution** will benefit human and nonhuman **components of the system** by explaining how it will **cause** changes in the **flow of matter and energy (effect)**. (SEP: 6.5; DCI: ETS1.C, LS1.C3; CCC: 2.3)

**What to do:** Circulate around the room and listen for student ideas on how the criteria and constraints that they are considering apply to what they know about the flow of matter and energy in their system. Ask students to predict what changes they will see in the community if their criteria are met. Provide feedback on where they are on the right track and where they need to be more specific. Prompt them to revisit ideas from models and case studies from previous lessons. Direct them to identify the specific components they want to change and to talk through their ideas first. Ask where they want to see matter and energy in the system.

**Building toward 11.A.** Design and refine **simpler criteria** for a **fire management solution** with the **desired effect** of reducing risk and balancing matter and energy **in the system**. (SEP: 6.5; DCI: ETS1.C; CCC: 2.3)

## 7 · NAVIGATE

2 min

**MATERIALS:** *Prioritizing Criteria/Constraints*

 **Prepare for home learning.** Display *slide L*. Celebrate students' progress in prioritizing criteria as the first step to designing solutions in various fire management systems. Ask students, *What are some potential solutions for fire management to meet your prioritized criteria? How can we ensure that our solutions best fit the communities we care about?* Listen for students to recognize that they need to hear from interest holders and trusted community members. Send students home with *Prioritizing Criteria/Constraints* and ask them to share their progress with their trusted community members. They should discuss their ideas for solutions that would address the prioritized criteria and record them in question 5 on *Prioritizing Criteria/Constraints*. Explain that you will begin the next class by sharing the ideas they gather from the community, then spend time refining and sharing their solutions.\*

## HOME LEARNING OPPORTUNITY



Home learning is an important place to do cultural formative assessment (Penuel, Shepard, & Davidson, 2016) where students bring ideas generated in their home into school or vice versa. By encouraging students to go get ideas from their communities, you are blurring the boundaries of home and school learning and making for a more meaningful and integrated science experience.

## End of day 1

### 8 · NAVIGATE: SHARE HOME LEARNING

5 min

MATERIALS: *Prioritizing Criteria/Constraints*, Class list from day 1

**Share home learning in groups.** Display **slide M**. Ask students to share the solutions they discussed in their home learning. Discuss which solutions they think will be most effective for fire management and possible constraints that may arise from implementing those solutions.

### 9 · INTRODUCE TRADE-OFFS

7 min

MATERIALS: science notebook

**Share possible solutions and constraints.** Display **slide N**. Ask each group to share solutions. They should also share the ways the solutions address both the criteria and constraints they identified. Ask other groups to comment on the feasibility of the proposed solutions and other possible constraints they had not considered. Keep a running record of solutions and constraints on the board.

| Suggested prompt                                                                                                   | Sample student response                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>What are some solutions you think would address the criteria and constraints in our fire management system?</i> | Responses will vary based on solutions.<br><br>We should have homeowners clear out brush and dead leaves that could burn in a fire.<br><br>We should make a plan to do controlled burns in areas where there is a lot of excess plant matter.                                                    |
| <i>What are some potential constraints that could affect the success of the solution?</i>                          | Responses will vary based on solutions.<br><br>People might not want to make changes to their property.<br><br>It might cost a lot of money.<br><br>People might be worried about controlled burns, and animals might lose their homes when removing trees or other plants to reduce fuel loads. |
| <i>How can we address the constraints to make it more likely that our solutions would be put in place?</i>         | We might need to give up something important to us to make the solution work for others.<br><br>We might need to talk to people with different ideas.                                                                                                                                            |

**Introduce the term *trade-off* and add it to Personal Glossaries.** Display **slide O**. When students mention that the needs of some community members might conflict with other community members, nonhuman species, places, lands, and waters, say, *Scientists and engineers call those conflicting priorities “trade-offs.”* Ask students to add an entry to their Personal Glossaries using words, pictures, and examples.

**Revisit potential trade-offs in case studies.** Call on students to review potential trade-offs that may have been at play in any of the case studies from Lesson 10 we read before as they begin to identify them in their own solutions. Record ideas on the whiteboard as you discuss. How do these trade-offs compare to what you are considering right now? Listen for students to mention a few ideas, such as:

- Prescribed burning still puts carbon dioxide in the atmosphere in order to reduce larger fires putting even bigger amounts of carbon dioxide into the atmosphere.
- If they do prescribed or cultural burning, there are safety concerns. They could accidentally burn down buildings or other structures they do not want to burn.
- It is labor-intensive and expensive to do yearly prescribed or controlled burns. But it might be more expensive in the long run if there is a larger fire.
- If cattle were used as grazers on some lands, people might be upset who wanted to use the lands for different purposes.
- Cattle release methane, which is contributing to climate change by releasing more carbon into the atmosphere.
- If they only plant trees, they may not help other species that need critical help after a fire.
- It can take a long time to build trust between groups like the Dja Dja Wurrung and the government of Victoria. Actions need to be taken more quickly.

#### ADDITIONAL GUIDANCE

Community partnerships are a great way for groups of like-minded individuals to come together and pool their resources to affect change in their community around an issue that they are passionate about, as students saw in the Lesson 10 case studies. In order to create an inclusive fire management system, students will need to consider multiple perspectives, and a community partnership is a great way to do so. If students do not bring up building partnerships in their fire management solution, ask, *How could partnerships impact how community members view your solution? How could their perspectives help you think of other potential trade-offs?*

Listen for ideas such as:

- The Dja Dja Wurrung are a great example of an interest group and government working together. Community members may trust the policy more from the government because both parties worked together to create common goals and to manage trade-offs.

## 10 · DESIGN A FIRE MANAGEMENT SYSTEM

10 min

**MATERIALS:** *Prioritizing Criteria/Constraints, Designing Fire Solutions*



**Design solutions in a fire management system.** Say, *Because we need to consider the trade-offs between criteria and constraints, let's see if we can propose solutions now that take them into consideration. Look at your criteria and constraints on Prioritizing Criteria/Constraints and decide how a solution can consider both of them. Make sure your choices consider humans, nonhumans and places, lands, and waters. Think about the trade-offs of prioritizing one group over another.* Display **slide P**. Distribute *Designing Fire Solutions*, organize students in their day 1 groups, and have them bring their *Prioritizing Criteria/Constraints*. Prompt them to figure out effective solutions that address their criteria. After they complete the table in question 1, groups should complete the handout to develop their full solution. These questions will help them more fully describe the intended effects and potential barriers to implementing their solution. Explain that *Designing Fire Solutions* will become a draft of their fire management system. \*

#### \* ATTENDING TO EQUITY

There are instances where the classroom community does not represent the larger community. If this is the context in which your students are working, it is imperative that you guide your students in taking inventory of the many groups that could be impacted by their solutions, especially the marginalized groups in the areas that they have a connection to, to prevent the unintentional perpetuation of oppressive systems when developing their solutions. Support them by having them revisit their research about the vulnerable populations in their community to see if there is potential for conversations where individuals from these vulnerable populations could share

## ASSESSMENT OPPORTUNITY

### What to look for/listen for in the moment:

- Students reference specific aspects of **simpler criteria** in their **solution** and how they would **change the matter and energy flow** in the **system to produce an effect**. (SEP: 6.5; DCI: ETS1.C, LS1.C3; CCC: 2.3)
- Students provide reasoning for each change (**effect**) that is connected to the **criteria for the solutions** they propose (**cause**). (SEP: 6.5; DCI: ETS1.C; CCC: 2.3)
- Students' changes (**cause**) are contextual, **based on scientific knowledge**, and tied to the specific **interest holders** and community for which they are designed (**effect**). (SEP: 6.5; DCI: ETS1.C; CCC: 2.3)

**What to do:** If students struggle to communicate how their specific solutions impact the ecosystem, refer them to the prompts on *Designing Fire Solutions*. Refer them to *Fire Management Study* and the class consensus model from Lesson 9 they revised during Lesson 10 after reading their case study. Ask them to explain how the case studies from Lesson 10 changed the flow of matter and energy in the system. Ask them to recall who or what caused the changes that impacted the solutions they read. If groups need additional support, *Fire Solutions Sample* provides sample responses that may help prompt individual groups refine their answer.

**Building toward 11.B** Design and refine a solution for fire management (based on **simpler criteria**) to **reduce risk and balance matter and energy in the system**. (SEP: 6.5; DCI: ETS1.C & LS1.C3; CCC: 2.3)

their experiences that could help students celebrate the richness of the spaces they are protecting and make their solutions more inclusive.

## 11 · CREATE FIRE MANAGEMENT SYSTEM PRODUCTS

20 min

### MATERIALS: *Designing Fire Solutions*

**Discuss how to effectively share fire management systems.** Display slide Q. Say, *Now that we have designed our fire management systems, we get to decide how we are going to share them. You will orally explain this to other students and support your explanation with another medium, like a visual or audio product. How can a visual product support your explanation and make it more persuasive?* Offer student groups a choice of products such as a poster, a video, a Powerpoint/Google Slides presentation, etc., based on available resources in your classroom/school. Encourage students to be creative by including at least 2 different formats: graphic, textual, visual, etc., and to choose the product that best fits their intended message and audience. Use the prompts below to support students in brainstorming ways to revise the solution from *Designing Fire Solutions*.

| Suggested prompts                                                                  | Sample student responses                                                                                   | Follow-up questions               |
|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|-----------------------------------|
| <i>How can you convey your priorities and how you came to make your decisions?</i> | <p>We would talk about what we valued most.</p> <p>We would talk about how we managed the constraints.</p> | <i>What about the trade-offs?</i> |

### \* ATTENDING TO EQUITY

#### Supporting emergent multilinguals.

Students should be encouraged to record their ideas using linguistic (e.g., written words) and nonlinguistic modes (e.g., drawings, tables, graphs). This is especially important for emerging multilingual students because making connections between written words and nonlinguistic representations helps students generate richer explanations of how fire management systems work.



| Suggested prompts                                                                                 | Sample student responses                                                                                                                                                                                                                           | Follow-up questions                                     |
|---------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| <i>What are effective ways to share your solution with others to inspire them to participate?</i> | <p>Share our priorities and how they relate to their priorities.</p> <p>Make participation in a solution relatively easy to do.</p> <p>Use visuals to support our explanation: make a list, drawings, video, model, or map about our solution.</p> | <i>What makes something easy to understand quickly?</i> |

**Create fire management system products.** Display **slide R**. Distribute appropriate materials to each group. Encourage students to reduce the amount of text in their products--the goal is not simply to copy *Designing Fire Solutions* into different formats. The product aims to explain or show how the solution will affect at-risk fire systems/communities and how those solutions will benefit humans, nonhumans, and the ecosystem's places, lands, and waters to as many different people as possible. General guidelines for the components of the product are listed on **slide R**. In addition, students can structure their products based on their message and intended audience. \*

Students should work in their groups to figure out how to communicate their fire management systems. Use the following prompts to check in with groups as you circulate around the room.

- How can you explain the way your solution will reduce the risk of fire in our community?
- How will you communicate in a way that engages with multiple interest holders?

#### ALTERNATE ACTIVITY

**Extension opportunity:** Challenge students to research the latest fire management technology and include it in their fire management systems. Ask them for examples of technology that could be used and have them add them to their solutions to get to their goal of balancing the flow of matter and energy in the system they care about. You could offer suggestions such as the use of drones in early fire detection, GIS, early warning systems, etc.

## 12 · NAVIGATE: SOCIAL EMOTIONAL CHECK-IN

3 min

**MATERIALS:** science notebook

**Create a personal reflection moment.** Display **slide S**. Say, *Now that you have created a fire management system for your community, take a moment to check in to see how you feel about what you have created.* Give students a few minutes to stop and jot their responses to the prompts on the slide in their science notebooks.

## End of day 2

### 13 · NAVIGATE: PREPARE TO PRESENT FIRE MANAGEMENT SYSTEM PRODUCTS

5 min

**MATERIALS:** *Peer Feedback Guidelines*, *Designing Fire Solutions*, fire management solution product

**Prepare students for peer feedback.** Display **slide T**. Ask a volunteer to remind everyone of what they did in the last class to make progress on our lesson question, *What decisions can we make to help manage fire in communities we care about?* Listen for them to share that they created a solution for fire management in their community in a format they could share.

**Discuss how peer feedback could improve their product.** Ask, *How can our classroom community help us improve our products?* Call on several students to share their responses. Listen for ideas such as:

- They can tell us what we did not communicate clearly.
- They may give us suggestions to more clearly communicate our ideas.
- We will hear about decisions that other groups made, which may give us new ideas.

**Review structures for peer feedback.** Say, *Let's engage in some peer feedback.* Display **slide U** and distribute *Peer Feedback Guidelines* or have students take out the copy you gave them in Lesson 7. Provide students with time to review the questions on the slide.

### 14 · COMMUNICATE FIRE MANAGEMENT SYSTEM PRODUCTS

10 min

**MATERIALS:** 3x3 sticky notes, *Designing Fire Solutions*, fire management solution product



**Share products.** Pair up two groups of students to communicate their fire management systems. One group will share their solution product for 3 minutes, and then the other will share. Encourage students to ask clarifying questions as they learn about another group's solution.

#### ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:**

- Students **communicate about their criteria and decisions for the specific tasks in the system, using multiple formats (e.g., orally, graphically, textually).** (SEP: 8.5; DCI: ETS1.C; CCC: 4.1)
- The **product students use to support their oral communication shows how their design solution affects the flow of matter and energy in the community.** (SEP: 8.5; CCC: 4.1)
- Students **communicate the trade-offs necessary for their design solution to work within the constraints of the system.** (SEP: 8.5; DCI: ETS1.C; CCC: 4.1)

**What to do:** If students struggle to communicate how their specific tasks in the system will change the flow of matter and energy, refer them to the class consensus model developed in earlier lessons to identify the specific components they changed. Students should discuss why they decided to show those ideas textually, with images, graphically, or some other appropriate representation.

**Building toward 11.C** Communicate scientific and technical information or ideas in multiple formats to **prioritize criteria and make trade-offs in the fire management system designed to change the flow of matter and energy.** (SEP: 8.5; DCI: ETS1.C; CCC: 4.1)

**Provide peer feedback.** Display **slide V**. Once students have explained their products to each other, ask individual students to provide feedback on the product that they heard about. Each student should use sticky notes to leave feedback on the other groups' fire management system product. Suggest that students write one idea on each sticky note, balancing praise and constructive critique.

**ADDITIONAL  
GUIDANCE**

Groups may prefer to confer with one another to coordinate their feedback to the group they heard. Each student should still write their own sticky note, but this will avoid duplication.

Once all students have provided feedback, give them a few minutes to read the sticky notes with their group and discuss how they could revise their fire management systems.

**15 · SELF-ASSESS PEER FEEDBACK ON FIRE MANAGEMENT**

5 min

**MATERIALS:** *Feedback Self-Assessment*

**Self-assess peer feedback.** Display **slide W**. Say, *Let's reflect on how this process went and think about next steps.* Distribute *Feedback Self-Assessment* and provide time for students to complete the questions. Collect *Feedback Self-Assessment* to assess what students learned from the process and how they would revise their fire management systems further.

**ALTERNATE  
ACTIVITY**

**Extension:** Spend additional time revising the proposed fire management systems and present them to decision-makers in the community who may be able to implement them.

## 16 · CLOSE THE DRIVING QUESTION BOARD

20 min

**MATERIALS:** *DQB Questions*, science notebook, Driving Question Board

**Return to the Driving Question Board.** Say, *Now that we have had a chance to think about fire management systems to help protect communities from fire, let's look back at our Driving Question Board. We have actually figured out a lot of things that we were wondering at the start of the unit that can help answer our unit question, What causes fires in ecosystems to burn and how should we manage them?*

**Evaluate which questions from the Driving Question Board were answered.\*** Display slide X. Have students take out *DQB Questions* from Lesson 6 and provide them with an updated version if you made one. Have students work in pairs for 5 to 10 minutes to mark questions they think the class has answered using the symbols on the handout, replicated here. Additionally, have students choose three questions to answer with evidence from their science notebooks.

- We did not answer this question or any parts of it yet: o
- Our class answered some parts of this question, or the ideas we developed help me see how I could now answer some parts of this question: ✓
- Our class answered this question, or using the ideas we developed, I could now answer this question: ✓+

**Annotate the DQB.** Display slide Y. Ask individual students to come to the DQB and mark questions that the class has answered in whole or in part through our investigations. Have as many students as possible participate until all the questions that the class has answered have been marked. If there is time, ask students to share evidence that we have answered the questions as each one is checked off. At the end, you may ask them to summarize which groups of questions have and have not been answered. Thank students again for all their hard work on this unit and celebrate just how much we have figured out through our efforts.

### ALTERNATE ACTIVITY

If you have time, have students choose one question from the DQB that has sticker dots for either categories ✓ or ✓+ to answer individually and then share their answer during the discussion.

Point to the questions that are still unanswered on the DQB. Tell students that over the course of future units, we will have to keep these questions in mind to see if we can answer them in the future.

### \* ATTENDING TO EQUITY

Revisiting the Driving Question Board is important for students to feel as though their questions are valued and recognized. While not all questions will have been addressed (it's more likely that 50–75 percent will be at least partially answered), this helps students see the hard work that they have done to answer many of their own questions.

## 17 · NAVIGATE

5 min

**MATERIALS:** *Fires Progress Tracker*

**Navigate.** Display slide Z. Say, *Last class, we updated our Progress Trackers, but it has been a while since we have reviewed what we have figured out. What else have we figured out that helps us explain “What decisions can we make to help manage fire in communities we care about?”* Direct students to revisit their *Fires Progress Tracker* rows from previous lessons, discuss with a partner, and complete the four columns in this lesson's *Fires Progress Tracker* section. An example Progress Tracker entry is provided below.

|  | What we figured out (WWFO) | How does WWFO help us make progress on our Driving Question about zombie fires? | How does WWFO connect to me or my community or have a larger-scale impact? | What questions do I have now? |
|--|----------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------|-------------------------------|
|  |                            |                                                                                 |                                                                            |                               |

|                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                 |                                                                                                                                                                                 |                                                         |
|----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| <b>Lesson 11:</b><br><b>What decisions can we make to help manage fire in communities we care about?</b> | -Criteria need to be broken down into simpler ones to manage fire so we can see who will be impacted (human and nonhuman) by our decisions.<br>-Making decisions involves and impacts people at many levels in the systems we care about.<br>-The places, lands, and waters we care about are complex, and decisions about the priority of certain criteria over others (trade-offs) may be needed. | There are a lot of different types of matter in the communities we care about, which means we have to break criteria down into smaller pieces to balance the matter and energy. | It is very complex to manage the needs of the communities we care about and at the same time make decisions that are best for balancing matter and energy in those communities! | We understand in this context, but is this always true? |
|----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|

**Turn and Talk.** Display **slide AA**. Use crosscutting concepts and science and engineering practices to review our progress. Ask students to turn and talk about the prompts to self-assess their progress out loud with a partner:

- How did constructing explanations/designing fire management systems over the course of this unit help us understand how to balance energy and matter in the zombie fire systems?
- How did thinking about energy and matter flows help us explain this system?

## Additional Lesson 11 Teacher Guidance

### SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

**CCSS.ELA-LITERACY.SL.9-10.4** Present information, findings, and supporting evidence clearly, concisely, and logically so that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.

Students present information when they design fire management systems in small groups and share them with the class.

# LESSON 12: Can we use everything we have figured out about fires to explain a new phenomenon?

## PREVIOUS LESSON

We designed fire management solutions for places, lands, and waters in our community. We broke down fire management criteria, identified constraints, and designed systems. We closed the Driving Question Board and revisited our Progress Trackers.

## THIS LESSON

PUTTING PIECES TOGETHER

1 day



Billy Nungesser, CC BY 2.0

We complete a transfer task about dead zones in marine ecosystems to demonstrate how what we figured out throughout the unit about the flow of energy and matter applies to other systems.

## NEXT LESSON

There is no next lesson.

## BUILDING TOWARD NGSS

HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3 HS-LS2-4, HS-LS2-5, HS-ESS2-6, HS-ETS1-2



## WHAT STUDENTS WILL DO

**12.A** Develop a model based on evidence to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, and hydrosphere. (SEP: 2.3; DCI: LS2.B, PS3.D; CCC: 4.3)

## WHAT STUDENTS WILL FIGURE OUT

- Carbon and oxygen cycle in systems such as the Gulf of Mexico, including the hydrosphere, atmosphere, and biosphere.
- Factors such as temperature and nutrient availability affect components of the system and can be observed through inputs and outputs of photosynthesis and carbon dioxide.

Lesson 12 • Learning Plan Snapshot

| Part | Duration |                                                                                   | Summary                                                                                 | Slide | Materials                                                   |
|------|----------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-------|-------------------------------------------------------------|
| 1    | 8 min    |                                                                                   | <b>NAVIGATE</b>                                                                         | A     | <i>Fires Progress Tracker</i>                               |
| 2    | 30 min   |  | <b>COMPLETE A TRANSFER TASK</b><br>Orient students to the transfer task and administer. | B     | <i>Dead Zone Transfer Task, Nitrogen Pollution By State</i> |
| 3    | 7 min    |                                                                                   | <b>NAVIGATE</b><br>Celebrate student accomplishments.                                   | C     |                                                             |

End of day 1

Lesson 12 • Materials List

|                  | per student                                                                                                                                                                                      | per group | per class |
|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------|
| Lesson materials | <ul style="list-style-type: none"><li>• <i>Fires Progress Tracker</i></li><li>• science notebook</li><li>• <i>Dead Zone Transfer Task</i></li><li>• <i>Nitrogen Pollution By State</i></li></ul> |           |           |

Materials preparation (10 minutes minutes)

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

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

Make sure key classroom artifacts like consensus models, the DQB, Related Phenomena, and Ideas for Investigation are available for students to reference in their celebrations and during the transfer task.



## Lesson 12 • Where We Are Going and NOT Going

### Where We Are Going

This final lesson concludes the unit. Students apply ideas, practices, and crosscutting concepts, especially about modeling, photosynthesis, cellular respiration, and carbon cycling. They use this knowledge for a Transfer Task related to the Gulf of Mexico's dead zone. The Transfer Task is aligned to one focal PE in the unit (HS-LS2-5) but requires that students leverage ideas from Life, Physical, and Earth Systems Science.

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

- PS3.D.3: The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. (secondary)
- LS2.B.3: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (HS-LS2-5)

Students use the science practice *developing and using models* to 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.

Students also use elements of the crosscutting concept Systems and System Models in their system models to help them explain the interactions and flows of energy and matter, such as how they think about how bacteria decompose more and more phytoplankton and convert more and more oxygen from the ocean into energy and carbon dioxide, and fertilizer runoff from farmlands results in extra nutrients in the ocean system.

Students will encounter *dissolved oxygen* in this lesson.

### Where We Are NOT Going

While the full performance expectation (HS-LS2-5) specifies the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere, this task focuses on the biosphere, atmosphere, and hydrosphere. In the unit, students figure out how carbon cycles through the geosphere in the context of peat.

# LEARNING PLAN for LESSON 12

## 1 · NAVIGATE

8 min

MATERIALS: *Fires Progress Tracker*, science notebook

**Review science notebook and Progress Tracker.** Display slide A. Say, *We have figured out a lot of great science ideas in this unit, but so far we have really only applied these ideas to fires. Today I want to invite you to learn about a new issue that is different from zombie and other fires but can be explained by looking at the flow of energy and matter through photosynthesis.*

Ask students to review *Fires Progress Tracker* and any additional materials they wish in their science notebooks to make note of what they figured out about photosynthesis and cellular respiration in the unit.

## 2 · COMPLETE A TRANSFER TASK

30 min

MATERIALS: *Dead Zone Transfer Task*, *Nitrogen Pollution By State*

**Orient students to the Dead Zone Transfer Task.** Display slide B. Distribute *Dead Zone Transfer Task* and give students a few minutes to read over the scenario and ask clarifying questions. Explain that *Nitrogen Pollution By State* has extra information they can use to answer question 12 if they want. Consider allowing your students to use their completed Progress Trackers to support them as they complete the Transfer Task. Consider reading the first two paragraphs out loud together as a class or having students volunteer to read out loud or with a partner. \* \*



**Administer the task.** Give students the rest of the period to complete the task, then collect assessments before students leave.

### ASSESSMENT OPPORTUNITY

**What to look for/listen for in the moment:** After students complete *Dead Zone Transfer Task*, use *Dead Zone Key* to evaluate their responses.

**What to do:** Provide feedback using *Dead Zone Key* as guidance.

**Building toward 12.A** Develop a model based on evidence to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, and hydrosphere. (SEP: 2.3; DCI: LS2.B, PS3.D; CCC: 4.3)

### \* ATTENDING TO EQUITY

**Universal Design for Learning:** Consider allowing students to *express* their understanding of the energy and matter flow in the dead zone in various ways for this assessment. This assessment encourages students to demonstrate their understanding of key skills and concepts from the unit so far through multiple modalities, including writing to explain and drawing models. Some students may benefit from using multiple modalities to show their thinking for any or all of the questions on this assessment.

You may consider allowing some students to present their answers verbally with you or with another student acting as a scribe to record their thinking on paper. Some students may benefit from using gestures, images, or manipulatives to support their explanations as opposed to written text. In each case, encouraging students to use multiple modalities to show their thinking creates a clear, accessible, equitable pathway for all students to demonstrate proficiency. Online tools such as Flipgrid can assist students in showing and explaining their ideas in more than just writing.

### \* ATTENDING TO EQUITY

### Supporting Emergent Multilinguals:

This assessment includes reference information on *Nitrogen Pollution By State*. As desired, support emergent multilinguals and other students who benefit from being presented with information in smaller chunks:

- by waiting to hand out *Nitrogen Pollution By State* until students reach that part of the assessment,
- or not using it entirely (and crossing off or deleting the text for question 12 that suggests using it).

## 3 · NAVIGATE

7 min

MATERIALS: None

**Frame the activity.** Congratulate students on all that they have figured out about the flow of energy and matter in complex ecosystems! Say, *We've figured out so much!*

**Close the unit.** Display **slide C**. Invite students to use the feelings wheel to reflect on how it felt to use what they figured out by investigating the zombie fire system to try to explain a new phenomenon.



## Unit B.2 Teacher Reference Materials



# ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

## Overall Unit Assessment

| When     | Assessment and Scoring Guidance                                                                                                                    | Purpose of Assessment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 1 | <p>Initial Models</p> <p><i>Arctic Fire Noticings/Wonderings</i><br/><i>Arctic Fire Noticings/Wonderings Key</i></p> <p>Driving Question Board</p> | <p><b>Pre-Assessment</b></p> <p>The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit.</p> <p>The <i>Arctic Fire Noticings/Wonderings</i> and initial model developed on day 2 of Lesson 1 is a good opportunity to pre-assess student understanding of matter and energy flow through the zombie fire system.</p> <p>The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as how and why questions, and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway.</p> |
| Lesson 2 | <p><i>Discussion Self-Assessment</i></p>                                                                                                           | <p><b>Self-Assessment</b></p> <p>Day 2 suggests an optional student self-assessment of their engagement in class discussions that contributed to the class moving their science thinking forward.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

| When     | Assessment and Scoring Guidance                                                                                                                                                                                                                                                                         | Purpose of Assessment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 3 | <p><i>Decomposition Investigation Planning Decomposition Investigation Planning Key</i></p> <p><i>Decomposition Investigation Data and Sensemaking Decomposition Investigation Data and Sensemaking Key</i></p> <p><i>Peat/Permafrost Explanation Peat/Permafrost Explanation Feedback Guidance</i></p> | <p><b>Formative</b><br/>On day 1, groups design an investigation to measure the effect of temperature on decomposition rates in yeast.</p> <p>On day 2, groups conduct an investigation to measure the effect of temperature on decomposition rates in yeast. They answer Making Sense questions about their results.</p> <p><b>Formative</b><br/>On day 4, students construct a written explanation for why there is so much carbon and energy in peat in the peat/permafrost system. A rubric is provided to support the scoring of this task.</p>                                                                                                                                                                                                                                                                                                                                                                                             |
| Lesson 4 | <p><i>Lesson 4 Exit Ticket (Electronic Exit Ticket)</i></p> <p><i>L4 Electronic Exit Ticket Key</i></p>                                                                                                                                                                                                 | <p><b>Formative</b><br/>This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 4. The first Electronic Exit Ticket allows relatively quick individual assessment of students on a key LLPE. Teachers can quickly check students' understanding of the relationship between the amount of solar radiation and photosynthesis and how it relates to changes in energy flow into and out of Earth as a system. Additionally, students have an opportunity here to reflect on how changes in solar radiation have impacted their own lives, how they used science and engineering practices and crosscutting concepts in sensemaking, and the value of their classmates in supporting their learning.</p>                                                                                                                                                                   |
| Lesson 5 |                                                                                                                                                                                                                                                                                                         | <p><b>Formative</b><br/>On day 1, students draft directional hypotheses about the relationship between available sunlight and the amount of carbon plants take in through photosynthesis. They then plan an investigation to produce evidence about the rate of photosynthesis related to angle of sunlight. Teachers provide feedback in real time using annotations of investigation plans.</p> <p>On day 2, teachers use prompts related to crosscutting concepts of matter and energy and systems and system models to support small-group sensemaking on data collected.</p> <p>On day 3, students cite evidence from their investigation when constructing oral explanations of the phenomenon. Teachers can circulate with a clipboard and roster to check that each student has cited evidence. Sample responses are included. Teachers may also provide students with the option to write or draw first before explaining verbally.</p> |

| When     | Assessment and Scoring Guidance                                                                                                                                                                                   | Purpose of Assessment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 6 | <p>Consensus Model</p> <p><i>Discussion-Mapping Tool</i></p> <p><i>Zombie Fire Explanation</i><br/><i>Zombie Fire Explanation Feedback Guidance</i></p>                                                           | <p><b>Formative</b><br/>Students develop a consensus model for zombie fires.</p> <p><b>Formative</b><br/><i>Discussion-Mapping Tool</i> is a tool to be used to track students' participation during one of this lesson's discussions. In this discussion, students make connections between their models and real-world phenomena that they have observed. Although it is important to assess whether students are able to use their models to explain phenomena, use of the discussion-mapping tool also allows for evaluation of the classroom culture at this point in time. Take steps to get more student voices on the table if there is not broad participation in the discussion.</p> <p><b>Summative</b><br/>Students put the pieces together to construct an explanation of how zombie fires could be burning under ice and releasing carbon dioxide. A rubric is provided to support the scoring of this task. Students have additional opportunities to figure out material in Lesson Set 2.</p> |
| Lesson 7 | <p><i>Making Sense of Case Studies</i><br/><i>Making Sense Key</i></p> <p>Carbon Sink Burning Models<br/><i>Peer Feedback Guidelines</i><br/><i>Sample Models</i></p> <p><i>Peer Feedback Self-Assessment</i></p> | <p><b>Formative</b><br/>On day 1, groups read one of 5 case studies about fire in a carbon sink and make sense of the case study together.</p> <p><b>Formative+Peer Feedback</b><br/>Students develop small-group models on day 1 for why each carbon sink is vulnerable to burning using the guidance provided in the Lesson 6 materials. On day 2, they give and receive peer feedback and revise their work.</p> <p><b>Self-Assessment</b><br/>Students reflect on their ability to give and receive peer feedback on day 2.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Lesson 8 | <p><i>CO2 Temperature Investigation</i><br/><i>CO2 Investigation Responses</i></p>                                                                                                                                | <p><b>Formative</b><br/>Students investigate the effects of increasing carbon dioxide on the temperature in a bottle. A sample key is provided on <i>CO2 Investigation Responses</i>.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

| When                    | Assessment and Scoring Guidance                                                                                          | Purpose of Assessment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 9                | <p>Consensus Model</p> <p><i>Lesson 9 Exit Ticket (Electronic Exit Ticket)</i><br/><i>Electronic Exit Ticket Key</i></p> | <p><b>Formative</b><br/>Students will put the pieces together to develop a model at multiple scales for the positive feedback effects of increasing carbon in the atmosphere and temperature. This model will be revisited in Lessons 10 and 11 as students investigate possible solutions for fire management. See the assessment guidance in the lesson for how to support students in the moment.</p> <p><b>Formative</b><br/>This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 9. This second and final Electronic Exit Ticket focuses on the models students developed to describe how energy from the Sun and wildfires drives the cycling of carbon and how it is connected to rising carbon dioxide concentrations and higher temperatures in the atmosphere. They reflect on the role of creating models and focusing on cycling carbon and energy play in their sensemaking. Finally, students again celebrate how they have helped the class make progress.</p> |
| Lesson 11               | <p>Fire Management Fire Solution</p> <p><i>Feedback Self-Assessment</i></p>                                              | <p><b>Formative</b><br/>Students use what they have figured out about the matter and energy flow in systems to develop a fire management solution that impacts a self-selected community, communicate it with their peers, and revise their choice of products based on teacher and peer feedback.</p> <p><b>Self-Assessment</b><br/>Students self-assess how they give and receive peer feedback after developing their solutions for fire management in a community they care about. See the assessment guidance in the lesson for how to support students in the moment.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Lesson 12               | <p><i>Dead Zone Transfer Task</i><br/><i>Dead Zone Key</i></p>                                                           | <p><b>Summative End-of-Unit Transfer Task</b><br/>Students will have the opportunity to demonstrate their competence with a Transfer Task, where they will develop models explaining what is happening with the matter and energy in a dead zone occurring in the Gulf of Mexico named for the thousands of fish that die all at once. This task is robust and will take approximately 30-45 minutes.</p> <p>The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the Scoring Guidance (key). Please use scoring that works for your class and your requirements. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments.</p>                                                                                                                                                                                                                                                                            |
| Embedded in each lesson | <p>Lesson-by-Lesson Assessment Opportunities (below)</p>                                                                 | <p><b>Formative Assessment</b><br/>Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |



| When                      | Assessment and Scoring Guidance                              | Purpose of Assessment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------|--------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Occurs in several lessons | <i>Fires Progress Tracker</i><br><i>Progress Tracker Key</i> | <p><b>Formative and Self-Assessment</b><br/>The Progress Trackers are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Trackers are meant to be a thinking tool for kids, we strongly suggest it is not collected for a summative “grade” other than for completion.</p> <p>In addition to this flexible resource, Progress Trackers have been written directly in the unit in Lessons 1, 2, 4, 5, 6, 7, 8, 9, 10, 11.</p>                                                                                                                                                                                                                                                 |
| Occurs in several lessons | Student Self-Assessment Rubrics                              | <p><b>Self-Assessment</b><br/>Student self-assessment rubrics for giving and receiving feedback can be used throughout the unit. Opportunities include, after a discussion or at the end of a class period. The rubric helps students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how the whole-class and small-group discussions can be more productive.</p> <p>Additional support can be found in the <i>OpenSciEd Teacher Handbook: High School Science</i>.</p> <p>In addition to this flexible resource, self-assessment has been written directly in the unit in Lessons 2, 7, and 11.</p>                                                                                                                                                                                                                                                                                          |
| Occurs in several lessons | Routines and Tools to Support Peer Assessment                | <p><b>Peer Assessment</b><br/>There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback. We suggest that peer feedback happen at least two times per unit.</p> <p>Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good opportunities to use a peer feedback protocol. They do not need to be final pieces of student work; rather, peer feedback will be more valuable to students if they have time to revise after receiving it. This should be a formative rather than summative type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities in which they can use these experiences as evidence for the feedback they give.</p> <p>Additional support can be found in the <i>OpenSciEd Teacher Handbook: High School Science</i>.</p> <p>In addition to this flexible resource, peer feedback has been written directly in the unit in Lessons 7 and 11.</p> |

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

## Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to [Science and Engineering Practice\(s\)](#), alignment to [Cross-Cutting Concept\(s\)](#), and alignment to the [Disciplinary Core Ideas](#).

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

| Lesson   | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 1 | <p><b>1.A Obtain information</b> about zombie fires to identify potential <b>cause and effect relationships</b> that lead to <b>changes in the biosphere and atmosphere</b>. (SEP: 8.1; DCI: ESS2.D.3; CCC: 2.2)</p> <p><b>1.B Develop a model</b> to explain how <b>matter (peat)</b> and <b>energy (fire)</b> flow in the zombie fire system. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)</p> <p><b>1.C Ask questions</b> to clarify how the <b>flow of energy and matter in the atmosphere</b> (CO<sub>2</sub>/smoke) and <b>biosphere(peat/permafrost)</b>, allows zombie fires to burn, <b>including the role of humans</b>. (SEP: 1.4; DCI: ESS2.D.3; CCC: 5.2)</p> | <p><b>1.A When to check for understanding:</b> On day 1, during the visual inquiry as students fill out their Notice and Wonder charts on <i>Arctic Fire Noticings/Wonderings</i>. In addition, you can also look for student ideas during the Initial Ideas Discussion.</p> <p><b>What to look for/listen for in the moment:</b> <b>Scientific and technical information obtained and communicated in writing</b> (SEP: 8.1):</p> <ul style="list-style-type: none"> <li>A <b>zombie fire</b> is when a fire burns <b>peat in/under the ice</b> near the Arctic Circle (where it is very cold) during the spring very close to where a previous <b>fire burned the fall before</b>. (DCI: ESS2.D.3; CCC: 2.2)</li> <li>Zombie fires happen more (<b>effect</b>) when the temperatures of the Arctic are <b>warmer during the summer months (cause)</b>. (DCI: ESS2.D.3; CCC: 2.2)</li> <li>Zombie fires are <b>causing</b> a lot of carbon dioxide to be released into the air/<b>atmosphere</b>. (DCI: ESS2.D.3; CCC: 2.2)</li> <li>A zombie fire is a recently discovered phenomenon that involves <b>living/once living things (biosphere)</b>, <b>ice/snow (cryosphere)</b>, and the <b>atmosphere</b>. (DCI: ESS2.D.3)</li> <li><b>Smoke containing carbon dioxide</b> travels very far from the fires (<b>a smaller system</b>) to big cities (<b>a larger system</b>), <b>causing</b> the air to be bad for breathing (<b>effect</b>). (CCC: 2.2; DCI: ESS2.D.3)</li> <li>Zombie and forest <b>fires</b> are <b>destroying a lot of habitat/ecosystems</b>. (CCC: 2.2; DCI: ESS2.D.3)</li> </ul> <p><b>1.B.1 When to check for understanding:</b> On day 2, when students develop their initial models.</p> <p><b>What to look for/listen for in the moment:</b> <b>Evidence</b> from the images, videos, data, and reading that shows <b>energy and matter flow within</b> the zombie fire <b>system and outside it</b> (such as plants, peat, snow/ice, fire, temperature changes, and atmosphere), including: (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)</p> <ul style="list-style-type: none"> <li>A potential mechanism for how <b>peat</b> could be releasing <b>carbon dioxide</b> when <b>burning</b>. (DCI: LS1.C.3; CCC: 4.3)</li> <li>Warmer temperatures in the zombie fire system mean more zombie fires burning for longer, and releasing more <b>carbon dioxide</b> might also mean more forest <b>fires</b> or more <b>carbon dioxide</b> released in general. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)</li> <li>Zombie fires being able to burn for a long time or the fires having enough <b>energy</b> to burn all winter/underground. (CCC: 4.3)</li> <li>Cold temperatures that have fire burning under ice, <b>warmer average temperatures</b> near the Arctic, greater <b>carbon dioxide</b> emissions in 2020, and <b>peat</b> deposits pictured <b>burning</b> at -60 degrees Celsius outside and releasing <b>smoke</b> from underground. (SEP: 1.4; DCI: ESS2.D.3; CCC: 4.2)</li> </ul> <p><b>1.B.2 When to check for understanding:</b> On day 2, when students revise initial models to develop the class consensus model.</p> <p><b>What to look for/listen for in the moment:</b> <b>Evidence</b> from the images, videos, data, and reading that shows <b>energy and matter flow within</b> the zombie fire <b>system and outside it</b> (such as plants, peat, snow/ice, fire, temperature changes, and atmosphere), including: (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)</p> <ul style="list-style-type: none"> <li>A potential mechanism for how <b>peat</b> could be releasing <b>carbon dioxide</b> when <b>burning</b>. (DCI: LS1.C.3; CCC: 4.3)</li> <li>Warmer temperatures in the zombie fire system mean more zombie fires burning for longer, and releasing more <b>carbon dioxide</b> might also mean more forest <b>fires</b> or more <b>carbon dioxide</b> released in general. (SEP:</li> </ul> |

| Lesson   | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                  | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|          |                                                                                                                                                                                                                                          | <p>2.3; DCI: LS1.C.3; CCC: 4.3)</p> <ul style="list-style-type: none"> <li>• Zombie fires being able to burn for a long time or the fires having enough <b>energy</b> to burn all winter/underground. (CCC: 4.3)</li> <li>• Cold temperatures that have fire burning under ice, <b>warmer average temperatures</b> near the Arctic, greater <b>carbon dioxide</b> emissions in 2020, and <b>peat</b> deposits pictured <b>burning</b> at -60 degrees Celsius outside and releasing <b>smoke</b> from underground. (SEP: 1.4; DCI: ESS2.D.3; CCC: 4.2)</li> </ul> <p><b>1.C When to check for understanding:</b> On day 3, when the class is building the DQB and during ideas for investigations. In addition, you can begin to see student questions on day 2 when students are recording initial questions.</p> <p><b>What to look for/listen for in the moment: Questions (SEP: 1.4) about:</b></p> <ul style="list-style-type: none"> <li>• Changes in <b>energy and matter</b> in the fire, peat, permafrost, <b>carbon dioxide</b>, and the <b>atmosphere</b>. (DCI: ESS2.D.3 &amp; ESS2.D.3; CCC: 5.2)</li> <li>• The <b>zombie fire system and surroundings/other interacting systems</b> that include <b>carbon dioxide</b>, fire, temperature, snow/ice, and the <b>atmosphere</b>. (DCI: ESS2.D.3; CCC: 5.2)</li> <li>• Human interactions that change the biosphere and atmosphere in ways that increase fire potential and the addition of carbon dioxide to the atmosphere. (DCI: ESS2.D.3; CCC: 5.2)</li> </ul>                                                                                                                                                                                                                                                                                                                            |
| Lesson 2 | <p><b>2.A Select appropriate tools to collect and record data in an ethical manner about the flow of energy and matter from the biosphere to the atmosphere as a result of burning.</b> (SEP: 3.3 &amp; 3.4; DCI: LS1.C.3; CCC: 5.4)</p> | <p><b>2.A.1 When to check for understanding:</b> On day 1, as students develop investigation plans.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>• <b>Evidence of energy and matter flow when burning</b>, such as matter in peat recombining to form carbon dioxide and water. (SEP: 3.4; DCI: LS1.C.3; CCC: 5.4)</li> <li>• <b>Ideas for tools to collect evidence of the flow of energy and matter when burning fuel samples.</b> (SEP: 3.4; DCI: LS1.C.3; CCC: 5.4)</li> </ul> <p>Note: At this stage, students need only to suggest a tool that makes sense, e.g., a device to measure carbon dioxide. They do not need to name a specific kind of tool.</p> <p><b>2.A.2 When to check for understanding:</b> On day 2, during the Building Understandings Discussion.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>• All the fuels have <b>carbon-based molecules</b> in them, but peat seems like it might have even more because the <b>BTB solution turned more yellow</b>. <b>More</b> carbon inside peat=more <b>carbon dioxide</b> in air. (SEP: 3.3; DCI: LS1.C.3)</li> <li>• All the fuels <b>produce energy</b> because we saw <b>light and measured a rise in temperature</b> when they burned, but peat kept burning for longer. (SEP: 3.3; CCC: 5.4)</li> <li>• The <b>burning moved the matter from the sugar molecules in the fuel to the carbon dioxide and water molecules in the atmosphere</b>. (DCI: LS1.C.3; CCC: 5.4)</li> <li>• <b>We did not need to track the exact amount of carbon dioxide</b>. Using the color change gave us relative amounts. (SEP: 3.4)</li> <li>• Doing the investigation as a class was an <b>ethical decision to keep excess carbon out of the atmosphere</b>. (SEP: 3.3)</li> </ul> |

| Lesson   | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                                                                                                                                                                                                                                          | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 3 | <p><b>3.A</b> Plan and carry out an investigation to produce evidence of changes to matter and energy flows in and out of a system during cellular respiration under different conditions. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)</p> <p><b>3.B</b> Construct an explanation for factors that affect cellular respiration, resulting in changes in the flow of matter and energy in the zombie fire system. (SEP: 6.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)</p> | <p><b>3.A.1 When to check for understanding:</b> At the end of day 1, when students complete <i>Decomposition Investigation Planning</i>.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>Energy and matter flow from sugar to yeast and carbon dioxide in the investigation. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4, CCC: 5.2)</li> <li>Data collection includes measuring carbon dioxide from the yeast after consuming sugar, conducting multiple trials, and/or comparing one groups' results to others for accuracy. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4)</li> </ul> <p><b>3.A.2 When to check for understanding:</b> At the end of day 2, when students complete <i>Decomposition Investigation Data and Sensemaking</i>.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>Energy and matter flow from sugar to yeast and carbon dioxide in the investigation. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)</li> <li>Data collection includes measuring carbon dioxide from the yeast after consuming sugar, conducting multiple trials, and/or comparing one groups' results to others for accuracy. (SEP: 3.2; DCI: LS2.B.1, LS1.C.4)</li> </ul> <p><b>3.B.1 When to check for understanding:</b> On day 3, when students complete an exit ticket.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>The highest rate of cellular respiration/decomposition would be represented by scenario A, where the greatest amount of matter is converted from plants to the atmosphere and the greatest amount of energy is transferred to the decomposers. (DCI: LS2.B.1, LS1.C.4; CCC: 5.2)</li> <li>In the future, if temperatures continue to rise and more peat is exposed to oxygen due to melting permafrost, the rate of cellular respiration/decomposition will increase. (DCI: LS2.B.1, LS1.C.4; CCC: 5.2)</li> <li>Explanations that include ideas that support the increase/decreased flow of energy/matter through cellular respiration/decomposition. (SEP: 6.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)</li> </ul> <p><b>3.B.2 When to check for understanding:</b> On day 4, when students construct their explanations for the large amount of peat in the Arctic and how it stores large amounts of energy and matter using <i>Peat/Permafrost Explanation</i>.</p> <p><b>What to look for/listen for in the moment:</b> See <i>Peat/Permafrost Explanation Feedback Guidance</i> for sample responses.</p> |
| Lesson 4 | <p><b>4.A</b> Make a claim regarding changes in energy flow between the Sun and the Arctic and the potential of solar energy to be captured and stored in plants through photosynthesis. (SEP: 6.1; DCI: PS3.D.3; CCC: 5.2)</p>                                                                                                                                                                                                                                  | <p><b>4.A When to check for understanding:</b> When students complete an Electronic Exit Ticket at the end of day 1.</p> <p><b>What to look for/listen for in the moment:</b> See <i>L4 Electronic Exit Ticket Key</i> for guidance.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

| Lesson   | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 5 | <p><b>5.A</b> Make a directional hypothesis to specify what happens to energy and matter flow through photosynthesis (dependent) when the amount of solar energy (independent) changes. (SEP: 3.5; DCI: LS1.C.1; CCC: 5.2)</p> <p><b>5.B</b> Plan and carry out an investigation, considering type, amount, and accuracy of data, to support explanations about changes in energy flow during photosynthesis under different conditions. (SEP: 3.2; DCI: LS1.C.1; CCC: 5.2)</p> <p><b>5.C</b> Apply scientific reasoning to link evidence to claims about how energy from the Sun drives the flow of matter from carbon dioxide in the atmosphere to sugar molecules assembled into larger molecules found in peat. (SEP: 6.4; DCI: LS1.C.2; CCC: 5.4)</p> | <p><b>5.A When to check for understanding:</b> On day 1, when students develop directional hypotheses.</p> <p><b>What to look for/listen for in the moment:</b> Directional hypotheses (SEP: 3.5) that identify:</p> <ul style="list-style-type: none"> <li>Solar radiation/light energy as the independent variable. (SEP: 3.5; DCI: LS1.C.1; CCC: 5.2)</li> <li>Photosynthesis and carbon stored in plants as the dependent variable. (SEP: 3.5; DCI: LS1.C.1; CCC: 5.2)</li> </ul> <p><b>5.B.1 When to check for understanding:</b> On day 1, when students develop investigation plans.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>Varying amounts/intensity/direct light energy. (LS1.C.1; CCC: 5.2)</li> <li>A way to measure the flow of matter and energy from the Sun, the carbon dioxide, and water to the plants. (SEP: 3.2; LS1.C.1; CCC: 5.2)</li> <li>Plans to collect enough and accurate data by compiling and comparing class data. (SEP: 3.2)</li> </ul> <p><b>5.B.2 When to check for understanding:</b> On day 2, when students engage in small-group sensemaking and complete <i>Tilt: Making Sense</i>.</p> <p><b>What to look for/listen for in the moment:</b> Student identification of evidence generated from their investigations, such as (SEP: 3.3):</p> <ul style="list-style-type: none"> <li>When the energy from the lamp was direct, more energy flowed to the plants, more carbon dioxide from the water was captured by the plants during photosynthesis and converted into sugar. (DCI: LS1.C.1; CCC: 5.2)</li> <li>When energy from the lamp was less direct, less energy flowed to the plants, more carbon dioxide stayed in the water in the test tube/less was captured by the plants during photosynthesis. (DCI: LS1.C.1; CCC: 5.2)</li> </ul> <p><b>5.C When to check for understanding:</b> On day 3, when students provide evidence for a claim.</p> <p><b>What to look for/listen for in the moment:</b> Evidence to support the claim (SEP: 6.4), such as:</p> <ul style="list-style-type: none"> <li>In direct light, more carbon dioxide from the water flowed into the plants through photosynthesis. (DCI: LS1.C.2; CCC: 5.4)</li> <li>Plants in direct light converted sugars to starch, and plants in the dark did not. (DCI: LS1.C.2)</li> <li>The energy from the Sun drives the flow of matter from the atmosphere to the plants. (DCI: LS1.C.2; CCC: 5.4)</li> </ul> |
| Lesson 6 | <p><b>6.A</b> Develop, revise, and use a model based on evidence to explain how inputs of matter and energy flow through different scales of the zombie fire system as the components are recombined to form different outputs. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)</p> <p><b>6.B</b> Construct an explanation based on evidence about how photosynthesis and cellular respiration change energy and matter in the biosphere, geosphere, and atmosphere and predict what might happen in the future. (SEP: 6.2; DCI: LS.2.B.3; CCC: 5.2)</p>                                                                                                                                                                                                                | <p><b>6.A When to check for understanding:</b> When students complete their Gotta-Have-It Checklists. In addition, you can listen for students to share ideas from their checklists during the following consensus model discussion.</p> <p><b>What to look for/listen for in the moment:</b> Students identify that their model needs to include relationships between matter and energy within the peat/permafrost system at various scales for explaining zombie fire. See specific components, interactions, and mechanisms in the example Gotta-Have-It Checklist. (SEP: 2.3; DCI: LS1.C.3; CCC: 4.3)</p> <p><b>6.B When to check for understanding:</b> On day 2, as students complete <i>Zombie Fire Explanation</i>.</p> <p><b>What to look for/listen for in the moment:</b> See <i>Zombie Fire Explanation Feedback Guidance</i> for guidance. (SEP: 6.2; DCI: LS.2.B.3; CCC: 5.2)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

| Lesson   | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 7 | <p><b>7.A</b> Critically read scientific literature adapted for classroom use to obtain information and summarize complex ideas about how changes to carbon sinks in ecosystems affect how matter and energy are exchanged between components of the system. (SEP: 8.1; DCI: LS2.B.3; CCC: 5.2)</p> <p><b>7.B</b> Develop, revise, and use a model to explain how energy and matter flow between the biosphere and atmosphere through biological processes and fire. (SEP: 2.3; DCI: LS2.B.3; CCC: 5.2)</p> | <p><b>7.A When to check for understanding:</b> On day 1, when students complete the Making Sense questions in <i>Making Sense of Case Studies</i>.</p> <p><b>What to look for/listen for in the moment:</b> Circulate around the room and listen to small-group discussions. Collect <i>Making Sense of Case Studies</i> and look for evidence of complex ideas from reading each case study (SEP: 8.1), such as:</p> <ul style="list-style-type: none"> <li>• The role of photosynthesis and cellular respiration in the movement of carbon in the biosphere and between the biosphere and atmosphere. (DCI: LS2.B.3; CCC: 5.2)</li> <li>• How changes in the system result in a buildup of carbon and energy that could burn. (DCI: LS2.B.3; CCC: 5.2)</li> <li>• The movement of carbon and energy from the biosphere to the atmosphere after/during a fire. (DCI: LS2.B.3; CCC: 5.2)</li> </ul> <p><b>7.B When to check for understanding:</b> On day 2, when students are sharing their small-group models. In addition, you can also look for student ideas on day 1, when students are developing their models, or later on day 2, when students are revising their models.</p> <p><b>What to look for/listen for in the moment:</b> System models based on evidence illustrating components, interactions, and mechanisms (SEP: 2.3) that include:</p> <ul style="list-style-type: none"> <li>• Energy from the Sun and matter from carbon dioxide in the atmosphere flowing to plants through photosynthesis. (DCI: LS2.B.3; CCC: 5.2)</li> <li>• Carbon (matter) from plants flowing to animals/decomposers and to the atmosphere through cellular respiration. (DCI: LS2.B.3; CCC: 5.2)</li> <li>• Energy and matter (carbon) from plants burning and flowing to the atmosphere as light, heat, and carbon dioxide. (CCC:5.2)</li> <li>• Factors that contributed to reduced flow of carbon (matter) resulting in build-up of carbon sink in the biosphere. (DCI: LS2.B.3; CCC: 5.2)</li> </ul> |

| Lesson   | Lesson-Level Performance Expectation(s)                                                                                                                                                                                   | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 8 | <p><b>8.A</b> Make a directional hypothesis to specify what happens to temperature (effect) when carbon dioxide concentrations in the atmosphere increase due to burning (cause). (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)</p> | <p><b>8.A.1 When to check for understanding:</b> On day 1, when students develop their directional hypotheses.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>A directional relationship between increasing carbon dioxide concentration and increasing temperature. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)</li> <li>Identifying that the carbon dioxide concentration is the independent variable and the temperature is the dependent variable in the bottle system. (SEP: 3.5; DCI: ESS2.D.3)</li> </ul> <p>See CO2 Investigation Responses for feedback guidance.</p> <p><b>8.A.2 When to check for understanding:</b> On day 2, when students turn in [BO.L8.HO] after having completed the investigation to check for student progress from day 1.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>A directional relationship between increasing carbon dioxide concentration and increasing temperature. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)</li> <li>Identifying that the carbon dioxide concentration is the independent variable and the temperature is the dependent variable in the bottle system. (SEP: 3.5; DCI: ESS2.D.3)</li> <li>While keeping everything else constant, the temperature increased faster and leveled off at a higher temperature in the bottle with the higher concentration of carbon dioxide than the control bottle to prove that carbon dioxide causes temperature to rise (effect). (DCI: ESS2.D.3; CCC: 2.2)</li> </ul> <p><b>Building toward 8.A.2</b> Make a directional hypothesis to specify what happens to temperature (effect) when carbon dioxide concentrations in the atmosphere increase due to burning (cause). (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)</p> <p><b>8.A.3 When to check for understanding:</b> On day 3, when students write a directional hypothesis to explain the relationship between carbon dioxide and temperature at the global scale.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>A directional relationship between increasing carbon dioxide concentration from fire in many ecosystems and increasing global temperature. (SEP: 3.5; DCI: ESS2.D.3; CCC: 2.2)</li> </ul> |



| Lesson   | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 9 | <p><b>9.A</b> Develop and use a complex, quantitative model that allows for manipulation to explain the flow of carbon (matter) and energy within and between the systems of the hydrosphere, atmosphere, geosphere, and biosphere through chemical, physical, geological, and biological processes. (SEP: 2.5; DCI: LS2.B.3; CCC: 4.3)</p> <p><b>9.B</b> Develop a model to explain how energy from the Sun and wildfires drives the cycling of carbon, leading to a rise in carbon dioxide concentrations and atmospheric temperatures. (SEP: 2.3; DCI: LS2.B.3, ESS2.D.3; CCC: 5.4)</p> | <p><b>9.A When to check for understanding:</b> On day 1 as students undergo the simulation and complete the Making Sense questions on <i>Carbon/Energy Quantitative Model</i>.</p> <p><b>What to look for/listen for in the moment:</b> See <i>Carbon/Energy Quantitative Model Key</i> for additional guidance. Look for students to quantify/measure the numerical differences in carbon and energy totals from their simulation.</p> <p><b>9.B.1 When to check for understanding:</b> On day 2, when students develop their Gotta-Have-It Checklists.</p> <p><b>What to look for/listen for in the moment:</b> Student checklist with evidence (SEP: 2.3) that includes:</p> <ul style="list-style-type: none"> <li>• Photosynthesis pulls carbon dioxide out of the atmosphere, where it can be stored in plants/plantlike organisms in the biosphere. (DCI: LS2.B.3; CCC: 5.4)</li> <li>• Cellular respiration releases carbon dioxide from living things in the biosphere into the atmosphere. (DCI: LS2.B.3; CCC: 5.4)</li> <li>• Wildfires that result from human activity release carbon dioxide from carbon stored in carbon sinks into the atmosphere, making it hotter. (CCC: 5.4; DCI: ESS2.D.3)</li> <li>• Energy from the Sun is transferred to carbon dioxide molecules in the atmosphere. (DCI: ESS2.D.3; CCC: 5.4)</li> <li>• Carbon can be stored out of the atmosphere for long periods of time in carbon sinks created by plants and can be altered by human activity. (CCC: 5.4; DCI: ESS2.D.3)</li> <li>• More carbon dioxide in the atmosphere leads to higher temperatures, more droughts, more fire, and more carbon dioxide in the atmosphere. (CCC: 5.4; DCI: ESS2.D.3)</li> </ul> <p><b>9.B.2 When to check for understanding:</b> When students complete an Electronic Exit Ticket at the end of day 2.</p> <p><b>What to look for/listen for in the moment:</b> See <i>Electronic Exit Ticket Key</i> for guidance on student responses.</p> |



| Lesson    | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 10 | <p><b>10.A</b> Apply scientific reasoning to link evidence behind approaches to fire management to support explanations about the flow of matter and energy through different levels of the ecosystem. (SEP: 6.4; DCI: LS2.B.2, CCC: 5.3)</p> <p><b>10.B</b> Use mathematical representations to support claims about the cycling of matter and flow of energy among organisms in an ecosystem. (SEP: 5.2; DCI: LS2.B.2, CCC: 5.3)</p> <p><b>10.C</b> Define the need for a plan to reduce the risk of wildfire in a community of concern and the social and environmental components that make the system likely to burn. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)</p> | <p><b>10.A When to check for understanding:</b> When students revise the Lesson 9 model in groups on day 1.</p> <p><b>What to look for/listen for in the moment:</b> Scientific reasoning that supports an explanation (SEP: 6.4) for each case study:</p> <ul style="list-style-type: none"> <li>Wisconsin Case Study (Case 1) and Cultural Burning Case Study (Case 3): Prescribed burning reduces the amount of carbon (matter) and energy in the carbon sink available to burn. (DCI: LS2.B.2; CCC 5.3)</li> <li>Animal Grazer Case Study (Case 2): Adding grazers to the model reduces the amount of carbon (matter) and energy available to burn because some of it moves from plants into animals. (DCI: LS2.B.2; CCC 5.3)</li> <li>Trees Case Study (Case 4): Planting trees moves carbon (matter) and energy in ecosystems by storing carbon from the atmosphere in trees. (DCI: LS2.B.2; CCC: 5.3)</li> </ul> <p><b>10.B When to check for understanding:</b> On day 2, when students use a mathematical representation of the matter and energy flow in the Serengeti ecosystem.</p> <p><b>What to look for/listen for in the moment:</b> Listen for the following as students build and revise their models in small groups:</p> <ul style="list-style-type: none"> <li>Energy from the Sun is used by plants to make plant biomass. (DCI: LS2.B.2; CCC: 5.3)</li> <li>Plants use some of the sugar they make from photosynthesis to carry out cellular respiration. (DCI: LS2.B.2; CCC: 5.3)</li> <li>When the grazers eat the plants, they use some of the energy/matter to do cellular respiration, some to make more biomass, and they get rid of some of it as waste. (DCI: LS2.B.2; CCC: 5.3)</li> <li>Decomposers break down the waste, use the energy for cellular respiration, make more biomass, and get rid of waste, also returning nutrients to the soil. (DCI: LS2.B.2; CCC: 5.3)</li> <li>More biomass exists in producers than consumers. (SEP: 5.2; DCI: LS2.B.2; CCC: 5.3)</li> <li>Only a small fraction of energy and matter is transferred to consumers. (SEP: 5.2; DCI: LS2.B.2; CCC: 5.3)</li> <li>Large amounts of energy and matter are used for cellular respiration to grow, move, for other life functions, or are lost as heat and are not available for consumption at the next level of the food web. (SEP: 5.2; DCI: LS2.B.2; CCC: 5.3)</li> <li>Matter is rearranged into different forms at each level of the food web. (DCI: LS2.B.2; CCC: 5.3)</li> </ul> <p><b>10.C When to check for understanding:</b> As students complete steps 1-4 of <i>Fire Risk Home-Learning</i> and share results with the rest of the class on day 3.</p> <p><b>What to look for/listen for in the moment:</b> The need for a plan in their community of concern that (SEP: 1.8):</p> <ul style="list-style-type: none"> <li>Protects fuel sources like homes and small parks from ignition. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)</li> <li>Include systems that protect vulnerable groups from harm. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)</li> <li>Includes perspectives and input from multiple groups to address all parts of the system that are likely to burn. (SEP: 1.8; DCI: LS2.B.2; CCC: 4.1)</li> </ul> |

| Lesson    | Lesson-Level Performance Expectation(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Assessment Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lesson 11 | <p><b>11.A</b> Design and refine simpler criteria for a fire management solution with the desired effect of reducing risk and balancing matter and energy in the system. (SEP: 6.5; DCI: ETS1.C; CCC: 2.3)</p> <p><b>11.B</b> Design and refine a solution for fire management (based on simpler criteria) to reduce risk and balance matter and energy in the system. (SEP: 6.5; DCI: ETS1.C &amp; LS1.C3; CCC: 2.3)</p> <p><b>11.C</b> Communicate scientific and technical information or ideas in multiple formats to prioritize criteria and make trade-offs in the fire management system designed to change the flow of matter and energy. (SEP: 8.5; DCI: ETS1.C; CCC: 4.1)</p> | <p><b>11.A When to check for understanding:</b> On day 1, when students complete <i>Prioritizing Criteria/Constraints</i> in small groups.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>Students articulate what effects their simple criteria for a proposed fire management solution will have for changing the flow of energy and matter in their chosen system. (SEP: 6.5; DCI: ETS1.C, LS1.C3; CCC: 2.3)</li> <li>Students describe how their simple criteria for their proposed fire management solution will benefit human and nonhuman components of the system by explaining how it will cause changes in the flow of matter and energy (effect). (SEP: 6.5; DCI: ETS1.C, LS1.C3; CCC: 2.3)</li> </ul> <p><b>11.B When to check for understanding:</b> On day 2, when students complete <i>Designing Fire Solutions</i> and create their fire management solution.</p> <p><b>What to look for/listen for in the moment:</b></p> <ul style="list-style-type: none"> <li>Students reference specific aspects of the simpler criteria in their solution and how they would change or refine within the matter and energy flow in the system for an enhanced or different effect. (SEP: 6.5; DCI: ETS1.C, LS1.C3; CCC: 2.3)</li> <li>Students provide reasoning for each change (effect) that is connected to the criteria for the solutions they propose (cause). (SEP: 6.5; DCI: ETS1.C; CCC: 2.3)</li> <li>Students' changes (cause) are contextual, based on scientific knowledge and tied to the specific stakeholders/interest holders and community for which they are designed (effect). (SEP: 6.5; DCI: ETS1.C; CCC: 2.3)</li> </ul> <p><b>11.C When to check for understanding:</b> On day 3, when students share their design systems for fire management.</p> <p><b>What to look for/listen for in the moment:</b> Refer to <i>Fire Solutions Sample</i> for guidance.</p> <ul style="list-style-type: none"> <li>Students communicate about their criteria and decisions for the specific tasks in the system, using at least two of the following formats: orally, graphically, textually, or another format. (SEP: 8.5; DCI: ETS1.C; CCC: 4.1)</li> </ul> |
| Lesson 12 | <p><b>12.A</b> Develop a model based on evidence to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, and hydrosphere. (SEP: 2.3; DCI: LS2.B, PS3.D; CCC: 4.3)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                               | <p><b>12.A When to check for understanding:</b> On day 1, when students complete <i>Dead Zone Transfer Task</i>.</p> <p><b>What to look for/listen for in the moment:</b> See <i>Dead Zone Key</i>.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |



# Lesson-Specific Teacher Materials

# Example Community Agreements

|                                                                                      |                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Respectful</b><br>Our classroom is a safe space to share.                         | <ul style="list-style-type: none"><li>• We provide one another with support and encouragement.</li><li>• We share our time to talk. We do this by giving others time to think and share.</li><li>• We critique the <i>ideas</i> we are working with but not the <i>people</i> we are working with.</li></ul>             |
| <b>Equitable</b><br>Everyone's participation and ideas are valuable.                 | <ul style="list-style-type: none"><li>• We monitor our own time spent talking.</li><li>• We encourage others' voices who we have not heard from yet.</li><li>• We recognize and value that people think, share, and represent their ideas in different ways.</li></ul>                                                   |
| <b>Committed to Our Community</b><br>We learn together.                              | <ul style="list-style-type: none"><li>• We come prepared to work toward a common goal.</li><li>• We share our own thinking to help us all learn.</li><li>• We listen carefully and ask questions to help us understand everyone's ideas.</li><li>• We speak clearly and loud enough so that everyone can hear.</li></ul> |
| <b>Moving Our Science Thinking Forward</b><br>We work together to figure things out. | <ul style="list-style-type: none"><li>• We use and build on others' ideas.</li><li>• We use evidence to support our ideas, ask for evidence from others, and suggest ways to get additional evidence.</li><li>• We are open to changing our minds.</li><li>• We challenge ourselves to think in new ways.</li></ul>      |

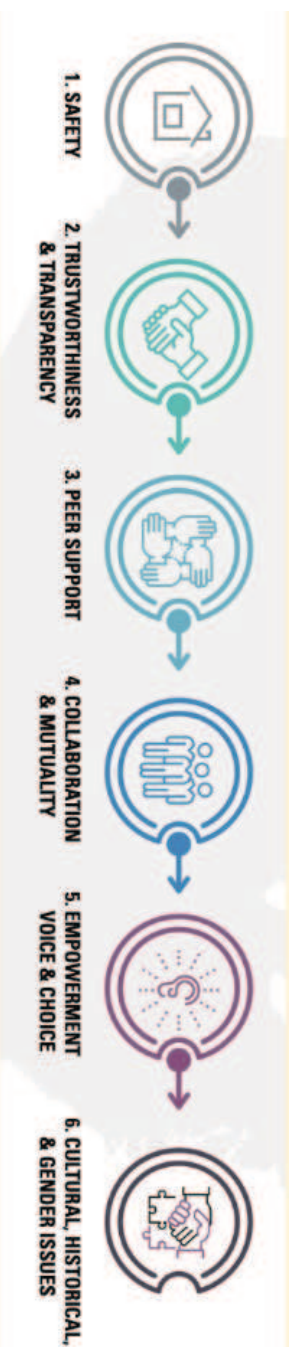


# Trauma-Informed SEL Supports

In this unit, students will investigate a puzzling Earth science phenomenon: fires are burning under ice and snow in the Arctic. Scientists in Alaska discovered burn scars from fires appearing very close to each other and that spring fires were starting very early in the year. Locals discovered smoke emerging from under the snow and ice. At the same time, scientists and local people noticed changes in the permafrost. It was thawing, cracking, and falling apart. Once living things that had been trapped in ice for thousands of years became exposed to air and warmth. As these overwinter, or zombie fires burn, scientists measured massive amounts of carbon dioxide and other gases being released into the atmosphere. This phenomenon provides the context in which to investigate the relationship between matter and energy within smaller-scale systems, ecosystems, and global-scale systems.

In this unit, students explore this relationship and deepen their understanding of how people around the world are addressing climate change, including zombie fires. We take a trauma-informed approach by providing accurate information and including information and prompts that help students explore how they can feel empowered addressing these issues in their own context. Learning about fires and climate change can be troubling and even heighten anxiety for students and adults alike, particularly if they have had previous exposure to traumatic events. Trauma reminders can be distressing <https://www.nctsn.org/resources/complete-x-trauma-facts-educators>. According to the CDC, “Adopting a trauma-informed approach is not accomplished through any single particular technique or checklist. It requires constant attention, caring awareness, [and] sensitivity.”

Trauma-informed approaches are designed to promote a positive, safe, and resilient learning experience for all students, regarding those who have experienced trauma. Six principles for trauma-informed approaches have been widely adopted.



CDC and Substance Abuse and Mental Health Services Administration

Strategies to Strengthen Trauma-Informed Approaches in the Classroom (adapted from <https://transformingeducation.org/>)

1. **Safety**
  - The classroom environment feels physically and psychologically safe
  - Interpersonal interactions between all educators and students promote a sense of safety
2. **Trustworthiness & Transparency**
  - Decisions about changes in the classroom are made with transparency
  - Building and maintaining trust among teachers and students, and between peers, is a top priority
  - Teachers openly acknowledge when they don't know an answer or when a subject could be hard to learn about for some people (adults and students alike).
3. **Peer Support**
  - Peer support, mutual help, and collaboration are foundational for establishing safety and hope in the classroom
4. **Collaboration & Mutuality**
  - The identities and stories of members of the school and classroom community are acknowledged and celebrated
  - Partnering on work (between teachers and students, and peer to peer)

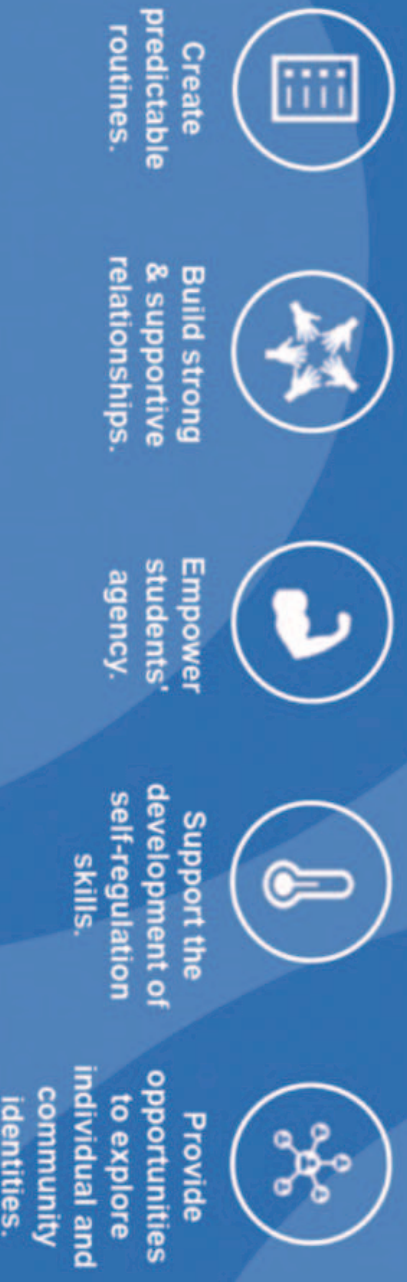
## 5. Empowerment, Voice & Choice

- There is meaningful sharing of power and decision-making when possible
  - Students' strengths and experiences are recognized and built upon
  - The school and classroom communities believe in its students' resilience, empowerment, and ability to make good choices
- ## 6. Cultural, Historical, & Gender Issues
- Members of the school and classroom community strive to move past cultural stereotypes and biases, promote culturally responsive teaching, and celebrate and welcome all students' identities

Social emotional learning (SEL) is the explicit teaching of skills to support emotion regulation and health relationships [https://casel.org/fundamentals-of-sel/?gclid=CjwKCAjwwb6lBhBJEiwAbuVVUStq6wDrY9Dbzq4VKmV13Aykf5H4NvfXzWHSBk9HWcIXoTkC7pbAClxoCbCOQAVD\\_BwE](https://casel.org/fundamentals-of-sel/?gclid=CjwKCAjwwb6lBhBJEiwAbuVVUStq6wDrY9Dbzq4VKmV13Aykf5H4NvfXzWHSBk9HWcIXoTkC7pbAClxoCbCOQAVD_BwE). Trauma-informed approaches integrated with SEL work towards ensuring all students, including those who have experienced trauma, have the skills, knowledge, and attitudes to regulate emotions and be productive, engaged learners <https://www.aier.org/sites/default/files/2021-09/Trauma-Sensitive-Schools-and-SEL-Integration-Brief-June-2021rev.pdf>; <https://transformingeducation.org/resources/trauma-informed-sel-toolkit/>. The following skills support the development of self-regulation, a key principle of trauma-informed SEL <https://transformingeducation.org/resources/trauma-informed-sel-toolkit/>.



# Key Trauma-informed SEL Practices



Transforming Education's Trauma-informed SEL Toolkit, CC BY-NC-SA 4.0

## Check, Reflect, Connect.

Throughout this unit, opportunities to develop self-regulation skills are embedded as optional activities using Check, Reflect, Connect.

- **Check.** Feelings awareness is a critical component of self-regulation and is included as standard practice in many social emotional learning programs <https://files.eric.ed.gov/fulltext/ED612292.pdf>. Students are invited to use a Feelings Wheel (see image below) to check with themselves about how they are feeling as they work through lessons. Key points to reinforce include:
  - A key to self-regulation is being able to acknowledge a person can feel multiple emotions at the same time, including seemingly “opposite” feelings. Encourage students to log these.
    - Ex) When learning about the zombie fires I felt curious and nervous.
- **Reflect.** Once a feeling is identified, taking a moment to reflect on the intensity of those feelings and what thoughts, past experiences, and beliefs may be related to those feelings is a key to self-reflective learning and developing regulation. The students are provided a space to jot down a couple notes or thoughts.
  - If reflecting is an emerging skill for your students, modeling and providing an example can be really helpful. This could be done for the full class or in small groups or one-on-one as needed.
- **Connect.** This is where students are empowered to rely on strong, supportive relationships and connect with a caring, supportive adult if they'd like to discuss their experiences within the lesson or unit. If needed, teachers can help students think about their connections at the beginning of the unit using the following strategies:
  - As students in their first Check, Reflect, Connect activity to identify at least one supportive adult they could talk with about their learning through the unit.
  - If a student is unable to identify someone, connect with them and help them think through options.
  - This person does not have to be a guardian or family member. Suggest adults such as a home room teacher, a neighbor, a member of their faith community, the parent of a friend, a coach.



# Engaging in Mindfulness

Mindfulness exercises can help all students regulate emotions, including those who have experienced trauma <https://transformingeducation.org/wp-content/uploads/2019/01/2019-BCRC-Mindfulness-Brief.pdf>. These strategies can help students feel more calm, centered, and ready to learn. These can be done before a lesson, mid-lesson, or at any point that you feel students might benefit from these strategies. They can also be done as a whole group, in small groups, or individually.

## Strategy #1: 5-4-3-2-1.

This strategy can be done either as a whole class, in partners, or small groups.

5- Look at five things around you. Make note of their qualities. What color are they? What shape are there? What other qualities do they have?

4- Acknowledge 4 things that you are touching or things you can touch. How do they feel? How would they feel?

3- Listen for 3 sounds you can hear. Tune into them individually.

2- Breathe in and identify two smells around you. What do these smells remind you of?

1- identify one thing you can taste around you. What would it taste like?

Some alternatives to this approach can be found at: <https://cognitiontoday.com/5-step-mindfulness-grounding-technique-to-ease-anxiety-why-it-works/>.

## Strategy #2: Check in

This strategy works well at the beginning of a lesson.

- Have students reflect on these questions:
- Think about the previous lesson. What went well? What was hard?
- Ask students to share their answers with peers and consider how they can become more invested and present in the lesson today.

## Strategy #3: Box Breathing

This strategy can be done at any point in a lesson, and can be helpful to do during or after any point where students show signs of stress or anxiety. Box breathing helps students with stress management and is broken down into 4 steps.

- Ask students to visualize a box with 4 equal sides in their minds. Guide students as each inhale or exhale takes them around the perimeter of the box.
- Step One: Breathe in through the nose for a count of 4.
- Step Two: Hold breath for a count of 4.
- Step Three: Breathe out for a count of 4.
- Step Four: Hold breath for a count of 4.
- Repeat

Note: The length of the steps can be adjusted to accommodate the individual (e.g. 2 seconds instead of 4 seconds for each step).

## Strategy #4: Progressive Muscle Relaxation

This strategy works well at any point during a lesson, individually, in small groups, or classwide as the teacher narrates. This exercise asks students to relax muscles in order through the body to help foster relaxation.

- **Step One:** Have students sit down and minimize distractions.
- **Step Two:** Starting at the feet, curl the toes under and tense the muscles in the foot. Hold for 5 seconds, then slowly release for 10 seconds. During the release, focus attention on the alleviation of tension and the experience of relaxation.
- **Step Three:** Tense the muscles in the lower legs. Hold for 5 seconds, then slowly release for 10 seconds. During the release, focus attention on the alleviation of tension and the experience of relaxation.
- **Step Four:** Tense the muscles in the hips and buttocks. Hold for 5 seconds, then slowly release for 10 seconds. During the release, focus attention on the alleviation of tension and the experience of relaxation.

- **Step Five:** Tense the muscles in the stomach and chest. Hold for 5 seconds, then slowly release for 10 seconds. During the release, focus attention on the alleviation of tension and the experience of relaxation.
- **Step Six:** Tense the muscles in the shoulders. Hold for 5 seconds, then slowly release for 10 seconds. During the release, focus attention on the alleviation of tension and the experience of relaxation.
- **Step Seven:** Tense the muscles in the face (e.g., squeezing eyes shut). Hold for 5 seconds, then slowly release for 10 seconds. During the release, focus attention on the alleviation of tension and the experience of relaxation.
- **Step Eight:** Tense the muscles in the hand, creating a fist. Hold for 5 seconds, then slowly release for 10 seconds. During the release, focus attention on the alleviation of tension and the experience of relaxation.

### Strategy #5: Guided Imagery

This can be done at any point in the lesson. Students visualize a relaxing environment to help manage stress, and walk through what they would sense in the environment. Guided imagery can be practiced individually or with the support of a narrator.

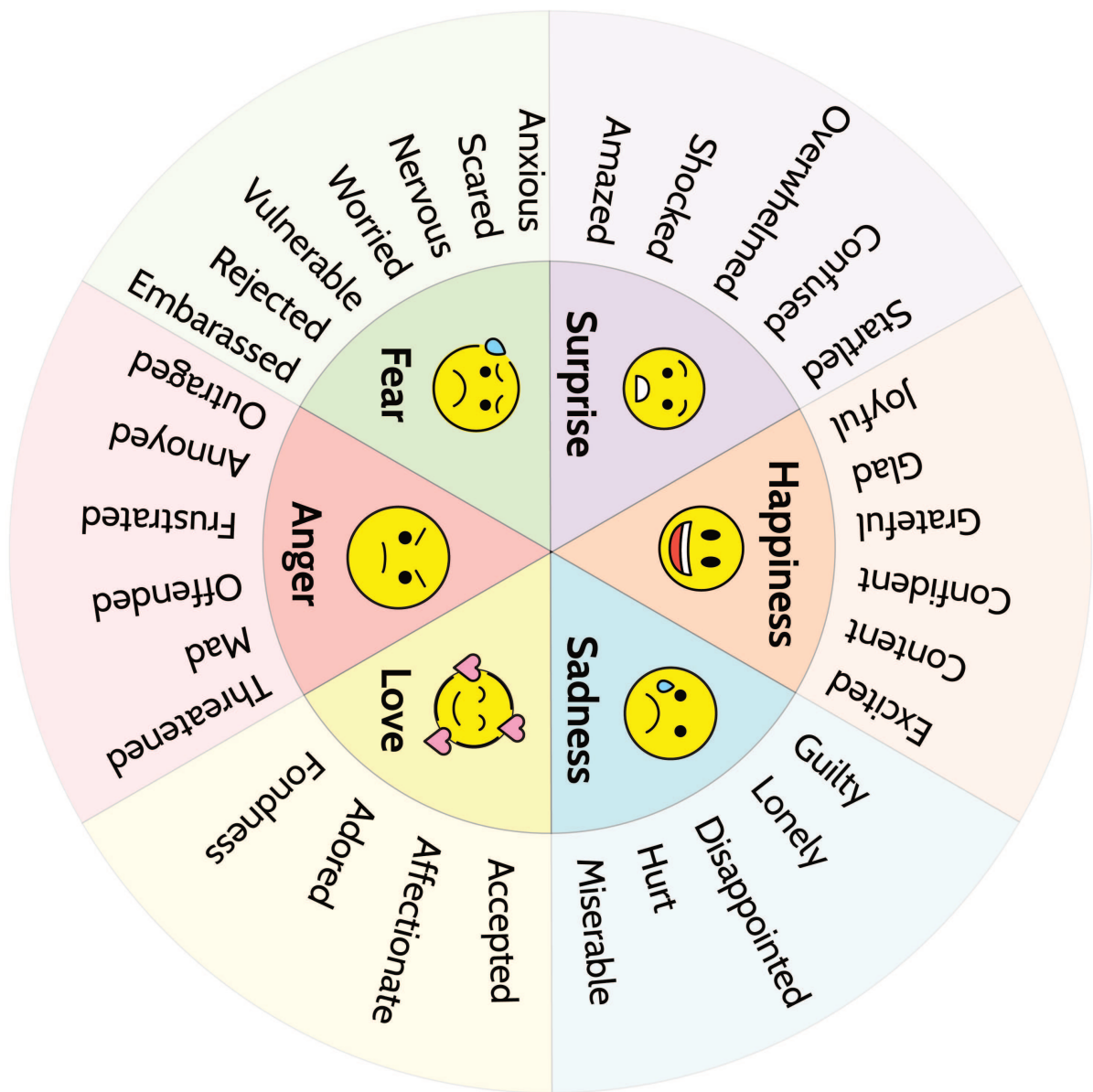
- **Step One:** Have students sit down. Ideally, the space will have minimal distractions.
- **Step Two:** Visualize a relaxing environment by either recalling one from memory or creating one through imagination (e.g., a day at the beach). Elicit elements of the environment using each of the five senses using the following prompts:
  1. What do you see? (e.g., deep, blue color of the water)
  2. What do you hear? (e.g., waves crashing along the shore)
  3. What do you smell? (e.g., fruity aromas from sunscreen)
  4. What do you taste? (e.g., salty sea air)
  5. What do you feel? (e.g., warmth of the sun)
- **Step Three:** Sustain the visualization as long as needed or able, focusing on taking slow, deep breaths throughout the exercise. Focus on the feelings of calm associated with being in a relaxing environment.

These are not the only mindfulness activities available for use. Consider using other mindfulness techniques as suggested by your school counselors. As experts in their fields, they can recommend strategies that are relevant and targeted to your specific students.

Strategies #2-#5 were adapted from the following source for classroom specific use:

Norell SK, Long A, Krepps JM. Relaxation Techniques. [Updated 2021 Sep 6]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: [video: OP.BOVID.L1.007]

- This resource cited above was released under a Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, duplication, adaptation, distribution, and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, a link is provided to the Creative Commons license, and any changes made are indicated.



- CASEL (2003). Safe and sound: An educational leader's guide to evidence-based social and emotional learning (SEL) programs. Chicago, IL: CASEL.
- CASEL (2015). CASEL guide: Effective social and emotional learning programs: Middle and high school edition. Chicago, IL: CASEL.
- Guiterrez, A. S., Krachman, S. B., Scherer, E., West, M. R., & Gabrieli, J. D. (2019). *Mindfulness in the Classroom: Learning from a School-based Mindfulness Intervention through the Boston Charter Research Collaborative*. BCRC. <https://transformingeducation.org/wp-content/uploads/2019/01/2019-BCRC-Mindfulness-Brief.pdf>
- National Child Traumatic Stress Network. (2014). Complex trauma: Facts for educators. Los Angeles, CA, & Durham, NC: National Center for Child Traumatic Stress.
- (n.d.). *Strategies to Strengthen trauma-informed Approaches in the classroom*. Transforming Education. Retrieved July 19, 2023, from <https://transformingeducation.org/>
- Norelli SK, Long A, Krepps JM. Relaxation Techniques. [Updated 2021 Sep 6]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: [video: OP.BOV.D.L1.007]
- Osher, D., Guarino, K., Jones, W., & Schanfield, M. (2021). Trauma sensitive schools and social and emotional learning: An integration. University Park, PA: Edna Bennett Pierce Prevention Research Center, The Pennsylvania State University.
- Wigelsworth, M., Verity, L., Mason, C., Humphrey, N., Qualter, P., Troncoso, P. (2019). Primary Social and Emotional Learning: Evidence review. London: Education Endowment Foundation. The report is available from: <https://files.eric.ed.gov/fulltext/ED612292.pdf>



# Arctic Fire Noticings/Wonderings Key

| Noticings                                       |                                                                                                                                                                                                                                                                                                                                                | Wonderings                                                                                                                                                                                                                                                                                                                               |  |
|-------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>Species, Kinds, and Behaviors</b>            | <ul style="list-style-type: none"> <li>There are a lot of different kinds of cool animals in the Arctic.</li> <li>Some of the animals are wild, and some live with people (domestic).</li> <li>Humans get injured when they have to fight the fires.</li> </ul>                                                                                | <ul style="list-style-type: none"> <li>How does the fire affect them?</li> <li>How many people live in the Arctic?</li> <li>How dangerous is it to be a firefighter?</li> <li>How is the government involved?</li> </ul>                                                                                                                 |  |
| <b>Relationships</b>                            | <ul style="list-style-type: none"> <li>Birds lose their habitat and food.</li> <li>It is getting hotter, and the snow is melting.</li> <li>Fires release carbon dioxide.</li> <li>The permafrost is thawing.</li> <li>Some years there are a lot of fires and not in other years.</li> <li>It is really cold where these fires are.</li> </ul> | <ul style="list-style-type: none"> <li>Will the birds be okay?</li> <li>Can we stop the snow from melting?</li> <li>What happens if the permafrost melts? What is permafrost?</li> <li>Why are there differences in how many forests there are/how much it burns year to year?</li> <li>How can fire burn when it is so cold?</li> </ul> |  |
| <b>Places, Lands, and Water</b>                 | <ul style="list-style-type: none"> <li>It is really weird to see all that smoke coming up from the snow.</li> <li>In the summer it looks really wet too.</li> </ul>                                                                                                                                                                            | <ul style="list-style-type: none"> <li>Do the fires melt the snow?</li> <li>How can there be fires with all that water?</li> </ul>                                                                                                                                                                                                       |  |
| <b>Thinking Across Scales</b>                   | <ul style="list-style-type: none"> <li>There were a lot of fires across Siberia in 2020-21.</li> <li>There are also a lot of forest fires here.</li> <li>The forest releases a lot of carbon dioxide.</li> <li>It looks like it has been getting worse since 2014.</li> <li>There is a lot of energy in the forest.</li> </ul>                 | <ul style="list-style-type: none"> <li>If nobody lives there, does it matter if it burns?</li> <li>What is the difference between a zombie fire and a forest fire?</li> <li>Is it bad that there is so much carbon dioxide released? Does that have to do with climate change/global warming?</li> <li>What is peat?</li> </ul>          |  |
| <b>Ethical Deliberation and Decision-Making</b> | <ul style="list-style-type: none"> <li>The firefighting sounds difficult.</li> <li>There is a lot of smoke that blackens the sky.</li> </ul>                                                                                                                                                                                                   | <ul style="list-style-type: none"> <li>Does firefighting cause even more damage to the ecosystem?</li> <li>Is the smoke harming people's health?</li> </ul>                                                                                                                                                                              |  |



# Burning Fuel Samples

Follow this general procedure for each fuel. Burn peat and at least one other material for comparison. Watch <https://youtu.be/wm--7z88KjQ> to see an example of how to burn fuel samples.

**Safety:** Use a vented hood when burning materials. Ensure burning materials have cooled completely before disposal. Ensure that the classroom has engineering controls (eyewash station and shower) available. Wear indirectly vented chemical splash goggles, a non-latex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity. Make sure students wear indirectly vented chemical splash goggles during the demonstration. Make sure students are a safer distance from the burning materials - at least 15+ feet during the demonstration. Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required. Immediately wipe up any spilled water on the floor--it is a slip and fall hazard. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair. Wash your hands with soap and water immediately after completing this activity. Never eat any food items used in a lab activity. Never taste any substance or chemical in the lab. The BTB solution is not hazardous, but if it comes into contact with the skin or eyes, rinse thoroughly with water for 15-20 minutes. If swallowed, get medical attention. Make sure that your school/district fire safety policies are in place with either water buckets, safety showers, and/or a fire extinguisher, ready to use.

**Gather your materials:** -peat and additional fuel samples -3 one-quart Pyrex™ storage containers -Bunsen burner or safety lighter -fireproof tongs -4 Petri dishes -aluminum foil sheets -flask of blue BTB -Windex or base such as NaOH -eye dropper/pipette -timers -gram scale -infrared thermometer -1000 mL beaker

To dilute the 0.04% BTB solution, add 25 mL of BTB (straight from the container) to a 1000 mL beaker. Add distilled water to the beaker until it reaches the 1000 mL line. The BTB solution should appear blue in color. If it does not, add a base, like Windex or NaOH, one drop at a time. Swirl after adding each drop and repeat as needed to create a blue color. Keep Windex on hand during the experiment to keep the starting color blue.

1. Ask a student to time the burning of each fuel sample.
2. If students want to measure mass loss, use a scale to mass each sample before and after it is burned.
3. Place a large piece of aluminum foil on the table to protect the surface where the glass container will be.
4. Pour an approximately 10 mL sample of blue BTB into two Petri dishes, enough to cover the bottom of each Petri dish. Use one Petri dish as a control and place one under the glass container where you will run the investigation.
5. If students want to measure temperature, ask a student to use the infrared thermometer to measure and record temperature.

For fuels, choose a small amount that will fit under the glass dish with the Petri dish. Use a small, thin (approximately 1.5 in long by ¼ in thick) piece of peat to facilitate lighting in a reasonable amount of time.

6. Use fireproof tongs to hold each sample over a burner flame, or use a safety lighter to ignite the sample. Some materials, like dried grass, should light quickly. Others, like wood, charcoal, or peat will take longer to catch. Peat, for example, will smolder (emit smoke) fairly quickly but may take up to five minutes to catch and sustain a full flame. Do not worry if the flame goes out when you move it into the glass container. Smoldering peat will still cause the BTB to change color. Watch [video:OP.BO.VID.L2.1000] to see an example.

7. After each fuel is lit, place it on top of the foil and invert the Pyrex™ container over the burning fuel and Petri dish of blue BTB solution. The foil may need to be folded up over the edge of the dish to contain smoke.

8. Allow it to burn or smolder inside the container for 5-10 minutes until you see a color change.

9. Students should record the time each fuel is placed inside the glass container as well as when they notice significant changes.

10. You may need to briefly lift up the container to see the BTB and swirl the solution gently in the Petri dish to complete a color change. Wait at least 5 minutes to do so to prevent gasses produced from dispersing before they impact the BTB.

11. Repeat the procedure for each fuel. Once you place each fuel under the glass, begin burning the next fuel sample. This will save time and hold student interest while you wait 5 minutes for the BTB to change color.



|        | Peat                    | Wood                                                                                                                                                                              | Leaves                                                                                                                     |
|--------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| Energy | Fuel temp before        | 25.7 °C                                                                                                                                                                           | 25.5 °C                                                                                                                    |
|        | Fuel temp after         | 41.3 °C                                                                                                                                                                           | 25.9 °C                                                                                                                    |
|        | Surrounding temp before | 25.3 °C                                                                                                                                                                           | 22.5 °C                                                                                                                    |
|        | Surrounding temp after  | 26.8 °C                                                                                                                                                                           | 25.8 °C                                                                                                                    |
|        | Burning time            | 10 min +                                                                                                                                                                          | 30 seconds                                                                                                                 |
| Matter | Other observations      | Hard to light. No visible flame, just a glowing ember at the beginning                                                                                                            | Difficult to keep lit. Short bright orange flame, went out before lid was on.                                              |
|        | Mass before             | 0.48 grams                                                                                                                                                                        | 0.48 grams                                                                                                                 |
|        | Mass after              | 0.04 grams                                                                                                                                                                        | 0.28 grams                                                                                                                 |
|        | BTB before              | Blue                                                                                                                                                                              | Blue                                                                                                                       |
|        | BTB after               | Green / Yellow                                                                                                                                                                    | Blue / Yellow                                                                                                              |
|        | Other observations      | Lots of smoke, condensation. Glass cover became cloudy and covered in droplets. Sample continued burning while taking mass after. Before was black, turned into a gray/white ash. | Was brown then turned black, then gray/white. After about 8 minutes, the smoke seemed to clear out of the glass container. |
|        |                         |                                                                                                                                                                                   | Brown, then black. Very little smoke because the fire went out quickly.                                                    |

# Decomposition Investigation Preparation

This plan will help you prepare materials for each group. The instructions include a few additional details not found in *Decomposition Investigation Data and Sensemaking*.

**Safety:** Students will be working with hot water. Ensure that students take appropriate precautions (including safety goggles, non-latex aprons, and nitrile gloves) and do not pour hot water into beakers. Use caution when working with heated liquids--these can burn skin! Immediately wipe up any spilled water on the floor--this is a slip and fall hazard.

## Materials:

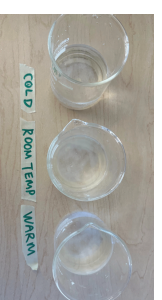
- safety goggles
- non-latex aprons
- nitrile gloves
- hot plate/hot water bath
- Ice/cold water bath
- 3 250-mL beakers per group
- Metric ruler
- 100 mL cold water (18 °C/64°F)
- 100 mL room temperature water (27 °C/80°F)
- 100 mL warm water (43 °C/110°F)
- 1.5 tsp/5 g yeast per beaker (1 packet = 7 g, note: packet size may vary)
- 2 0.5-teaspoon measuring spoons or gram scale
- 0.5 tsp/2 g granulated sugar per beaker
- 3 digital thermometers
- Optional: tape (labeling beakers)
- Optional: timer

## Student Plan:

### Investigative Question:

*How does temperature affect the flow of matter and energy from sugar/plants to carbon dioxide/atmosphere by decomposers in the zombie fire system?*

1. Prepare warm and cold water at volume large enough for the class using hot/cold water baths, a hot plate and/or ice.
2. Add 100 mL of water to each beaker. Beaker 1=cold water, Beaker 2=room temperature water, beaker 3=warm water.



3. Add 0.5 tsp or 2 grams of sugar to each beaker and stir until dissolved.
4. Add 1.5 tsp/5 g of yeast to each beaker and stir.



5. Record the amount of foam produced (in mm) every 2 minutes for 14-20 minutes.



### Recommendations:

- To save time, create a large volume of 2% sugar solution (20 g in 1000 ml water) ahead of time and distribute to each group as needed for their investigations.
- If water baths are available in your classroom, set up warm- and cold-water baths for students to place their investigation beakers in during the investigation to keep the water temperature steady. This is one way to provide more accurate results in a very warm or cold classroom.
- There are many alternative ways to measure carbon dioxide production in yeast, including:
  - A balloon over the tip of a flask with string to measure the diameter of the balloon over time.
  - A carbon dioxide probe to measure changes in carbon dioxide in the beakers.
  - Instead of beakers, place all ingredients in a clear, sandwich-size zipper bag and remove all of the air before sealing. Lay the bag flat on the table and measure the height of the bag over time.
- If using test tubes instead of beakers, ½ teaspoon of yeast in 25-30 ml of 2% sugar solution at ideal temperatures will provide an adequate response.

### Lesson 3: Answer Key 1

## Decomposition Investigation Planning Key

### Plan an Investigation Part 1: Identify Variables

How does a change in **TEMPERATURE (independent variable)** affect the flow of matter and energy from **SUGAR/PLANTS** to **CARBON DIOXIDE/ATMOSPHERE (dependent variable)** by decomposers in the zombie fire system?

1. Independent variable: **Temperature**

Think about:

- What **causes** there to be so much matter and energy in the peat?
- What affects how matter decomposes?
- What is changing or different in the zombie fire system?
- What variable will you change in your Decomposition Investigation to try to answer your question?

2. Dependent variable: **Amount of carbon dioxide**

Think about:

- What is the **effect** of the change you named above on matter and energy in the zombie fire system?
- What variable will you measure to collect evidence to answer your question?
- What **effect** will you see because of the change you make?

### Plan an Investigation Part 2: Set-Up

You will have access to materials such as beakers, water, yeast, sugar, rulers, and thermometers. When bakers work with yeast they prefer the following recipe to activate it:

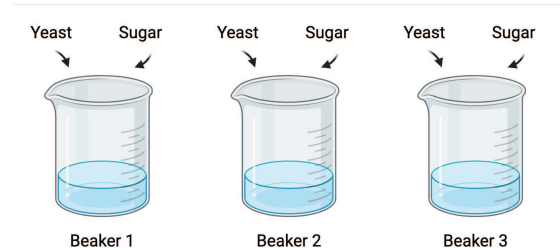
- Mix 1 teaspoon or 4 g sugar in 100 ml warm water (approximately 38–43°C or 100–110°F). Add 1 tablespoon or 10 grams of yeast. Mix.
- Look for bubbles in the yeast to indicate it has been activated and is consuming the sugar.
- Note: yeast cannot survive above 54°C or 130°F.

1. How will the beakers be similar to each other?

**They will all have water, sugar, and yeast.**

2. How will the beakers be different from each other?

**They will be kept at different temperatures.**



Illustrations created by OpenSciEd in BioRender

### Plan an Investigation Part 3: Data Collection

1. In your investigation you will collect data every 2 minutes for 14-20 minutes. See the data table below for an example. What will you measure and record in your data table to collect evidence to answer your questions about the flow of energy and matter?

We will measure the amount of carbon dioxide produced in the beakers (foam).

2. How much data will your class collect?

Each group will have 1 beaker of each type: low, medium, and high temperature.

3. How will you know if your data is accurate?

We can compare our data to other groups to see if they are similar.

| Time (min) | Beaker 1 (cold) | Beaker 2 (room temp) | Beaker 3 (warm) |
|------------|-----------------|----------------------|-----------------|
| 0          | 0               | 0                    | 0               |
| 2          | 0               | 0                    | 1               |
| 4          | 0               | 0                    | 4               |
| 6          | 0               | 2                    | 7               |
| 8          | 0               | 5                    | 10              |
| 10         | 0               | 10                   | 13              |
| 12         | 0               | 10                   | 13              |
| 14         | 0               | 11                   | 14              |
| 16         | 0               | 12                   | 14              |
| 18         | 0               | 12                   | 15              |
| 20         | 0               | 12                   | 15              |

# Decomposition Investigation Data and Sensemaking Key

Investigative Question:

*How does temperature affect the flow of matter and energy from sugar to carbon dioxide by decomposers in the zombie fire system?*

Table 1. Data table.

Note: Individual group results will vary.

| Time (min) | Beaker 1: Cold | Beaker 2: Room temperature | Beaker 3: Warm |
|------------|----------------|----------------------------|----------------|
| 0          | 0              | 0                          | 0              |
| 2          | 0              | 0                          | 1              |
| 4          | 0              | 0                          | 4              |
| 6          | 0              | 2                          | 7              |
| 8          | 0              | 5                          | 10             |
| 10         | 0              | 10                         | 13             |
| 12         | 0              | 10                         | 13             |
| 14         | 0              | 11                         | 14             |
| 16         | 0              | 12                         | 14             |
| 18         | 0              | 12                         | 15             |
| 20         | 0              | 13                         | 15             |

## Making Sense

1. Circle the words that best summarize what happened in your investigation.

More/Less sugar was converted to carbon dioxide at higher/lower temperatures. (or less and lower)

2. How was the flow of energy different at high temperatures compared to lower temperatures?

At higher temperatures, more energy from the sugar was transferred to the yeast than at lower temperatures.

OR

More energy went to carbon dioxide and/or heat in the atmosphere at higher temperatures.

3. Can all the matter and energy in the system be accounted for by measuring carbon dioxide? Explain your thinking

No, we only measured foam, which we think accounts for carbon dioxide. We do not know if the energy and matter in the sugar went to other places or if matter was rearranged into other things. It is possible that there is more yeast than before, but we did not measure that.

4. What does your evidence help you understand about:

a. What happened in the past that kept the matter in the peat from decomposing in the permafrost?

Which beaker best represents the past (circle one):

cold

room temp

warm

The peat has been cold and frozen in the permafrost. That has kept the rate of decomposition low/there has not been a lot of decomposition, so most of the matter and energy has stayed in peat in molecules like sugar.

b. What is different now that is causing zombie fires to burn?

Which beaker best represents the present (circle one): cold

room temp

warm

It is warming up and higher temperatures mean the ice is melting and fires can start. When fires start, they can burn for a long time because there is so much matter and energy in the peat.

c. What will happen in the future?

Which beaker best represents the future (circle one): cold

room temp

warm

It is getting warmer, so this problem will probably get worse as more of the ice melts.

# Peat/Permafrost Explanation Feedback Guidance

**3.B** Construct an explanation for factors that affect **cellular respiration** resulting in changes in the flow of **matter and energy** out in the zombie fire system. (SEP: 6.2; DCI: LS2.B.1, LS1.C.4; CCC: 5.2)

| 3D Elements Addressed in This Assessment |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SEP</b>                               | Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.                                                                                                                                                                                                                                             |
| <b>DCI</b>                               | <b>Photosynthesis and cellular respiration</b> (including anaerobic processes) provide most of the energy for life processes.<br><br>As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed; that can transport energy to <b>muscles</b> . Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. |
| <b>CCC</b>                               | 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.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

**Instructions:** Use evidence from your investigations to explain **why there is so much peat in the peat/permafrost system**. Use the space below to jot down some notes. Then write or draw your explanation on the next page.

| Gotta-Have-It-Checklist                                                                                                                         | Ideas for Sentence Starters                                                                                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Components of the system (living/non-living).</b>                                                                                            | <b>The peat/permafrost system is composed of...</b>                                                                                                      |
| <b>Interactions between components:</b><br>Flow of energy in/out/within the system. (CCC/DCI)<br>Flow of matter in/out/within the system. (CCC) | The energy starts out ____ and flows through ____ to ____.<br>The matter moves from ____ to ____ when ____.<br>____ slows down/speeds up the flow of ... |
| <b>Mechanisms that explain the interactions:</b><br>The role of cellular respiration. (DCI)                                                     | Cellular respiration affects the flow of matter and energy by...                                                                                         |
| <b>At least 2 pieces of evidence from our investigations in class. (SEP)</b>                                                                    | One piece of evidence I have to support my ideas is...                                                                                                   |



| 3D Elements | Foundational Pieces                                                                                                                                                                                                                                                                                                                             | Linked Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Organized Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|             | <p>In this explanation, look for:</p> <p>Students state a claim that the matter and <b>energy are staying in the peat/permafrost in the zombie fire system.</b></p> <p>Students reference evidence from either the Decomposition Investigation or the scientific study but do not connect to the peat/permafrost in the zombie fire system.</p> | <p>In this explanation, look for:</p> <p>Students' claims address the <b>effects of temperature or oxygen levels on the flow of matter and energy in the peat system, and that more energy and matter stay in the peat</b> but do not connect it to the rate of decomposition.</p> <p>Students reference evidence from the Decomposition Investigation or the scientific study but do not connect it to the rate of decomposition in the peat.</p>                         | <p>In this explanation, look for:</p> <p><b>The rate of decomposition is low when it is cold with low oxygen levels, and therefore flow of energy and matter is reduced. With these conditions, the rate of energy transfer from the peat to the atmosphere is reduced.</b></p> <p>Students can map how the Decomposition Investigation with yeast serves as a model for what happens to the peat. They can also reference the scientific study about oxygen levels.</p> <p>They can predict that in the future, if the atmosphere continues to warm, the increased temperature will speed up decomposition/cellular respiration, and the melting permafrost will expose more peat to oxygen, further speeding up the process.</p> |
| Example     | <p>The energy and matter stay in the peat.</p> <p>The sugar decomposed less in the cold, or the plants decomposed less when there was less oxygen.</p> <p>In the future, more decomposition will happen.</p>                                                                                                                                    | <p>The energy and matter stay in the peat. It is cold in the peat in the permafrost.</p> <p>The yeast did not convert much sugar to carbon dioxide when it was cold.</p> <p>Or</p> <p>The energy and matter stay in the peat. There is not very much oxygen in the peat in the permafrost.</p> <p>The yeast did not make carbon dioxide when it was cold.</p> <p>In the future, more decomposition will happen, and more carbon dioxide will end up in the atmosphere.</p> | <p>The energy and matter stay in the peat because the rate of cellular respiration is low in the cold permafrost. Evidence from other systems includes: the yeast converted more sugar to carbon dioxide at higher temperatures. Plant material decomposes faster with more oxygen.</p> <p>Peat forms in an environment with little oxygen and cellular respiration is slower.</p> <p>In the future, if the atmosphere continues to heat up, more decomposition/cellular respiration will happen and more carbon dioxide will be transferred to the atmosphere.</p>                                                                                                                                                                |

|                       |                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Feedback              | <p><i>Linking:</i><br/>Revisit the class consensus model and ask students to consider how the flow of matter and energy changed at different temperatures.</p> <p>Support students in seeing how the Decomposition Investigation with yeast can be a model of the zombie fire system.</p> | <p><i>Organizing:</i><br/>Review how decomposition rates affect the flow of matter and energy in both the Decomposition Investigation and how it relates to the zombie fire system.</p> <p>Ask students what other condition slows down the rate of decomposition.</p>                                                        | <p><i>Extending:</i><br/>Ask students to imagine another model or phenomenon that functions like the zombie fire system.</p> <p>Ask students to predict how matter and energy flow in that system.</p>                                                                                         |
| Ideas for Instruction | <p>If the majority of the class demonstrates foundational understanding, revisit the class consensus model. Ask small groups to work together to explain the model.</p>                                                                                                                   | <p>If the majority of the class demonstrates linking understanding, ask students to work in pairs to read one another's responses and identify what evidence was used to support the original response. Ask them to provide their partner with a suggestion for additional evidence they could connect to their response.</p> | <p>If the majority of the class demonstrates extending understanding, talk through other examples where environmental conditions change the rate of matter and energy flow during cellular respiration, such as hypothermia (cold conditions) or a sprinting human (anaerobic conditions).</p> |



## Lesson 4 Teacher Reference

# Exit Ticket Guidance

## What are Electronic Exit Tickets?

These are short **formative** assessments that occur 2-3 times per unit in between other assessments. They include items to check for understanding of lesson-level PEs, to make connections between content and students' lives, and to elicit information about their experiences and to help students reflect on their own progress in focal SEPs and CCCs. **They are built in Google Forms but can be ported to any survey software.**

## How to create Electronic Exit Tickets

In *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, the two

Electronic Exit Tickets in this unit are found:

- at the end of Lesson 4 (**slide M**);
- and at the end of Lesson 9 (**slide T**)

Select the link for the Electronic Exit Ticket that corresponds with the lesson you are teaching.

Lesson 4: [https://docs.google.com/forms/d/174jIzIx\\_-iElbRcNKnhTiv4SOtBpRT3e7c2lqlfyWJaI/copy](https://docs.google.com/forms/d/174jIzIx_-iElbRcNKnhTiv4SOtBpRT3e7c2lqlfyWJaI/copy)

Lesson 9: <https://docs.google.com/forms/d/1CEhuOcDuKY27Ph5v8jH3RBgVLkqlv9h48WoEaL7TA6Q/copy>

Spanish versions are available here:

Lesson 4: [https://docs.google.com/forms/d/1omOsDpFjUVoI8LPQKiL2l4sWAlYxe8C\\_fdlZpUdc7VQ/copy](https://docs.google.com/forms/d/1omOsDpFjUVoI8LPQKiL2l4sWAlYxe8C_fdlZpUdc7VQ/copy)

Lesson 9: <https://docs.google.com/forms/d/13iwwHiozMe5GqnXla4fKjCOGgT-k4pDjUagCDlrPzYA/copy>

### Attending to Equity

Some students may benefit from completing the Electronic Exit Tickets on a printed version. Complete the steps below to create a copy of the Electronic Exit Ticket. Once you have created a copy in your own Google Drive, click on the 3 dots on the upper right of the form next to the SEND button. This should give you the option to print a paper copy of the Electronic Exit Ticket.

When you select the link, it will ask you to make a copy in your own Google Drive.

## Copy document

Would you like to make a copy of **Family and Friends MRE Survey**?

Make a copy



The student survey will open in your own Google Drive.

Family and Friends MRE Survey ☆

Questions Responses

Family and Friends MRE Survey

⊕ ⌵ ⚙ Send ⋮

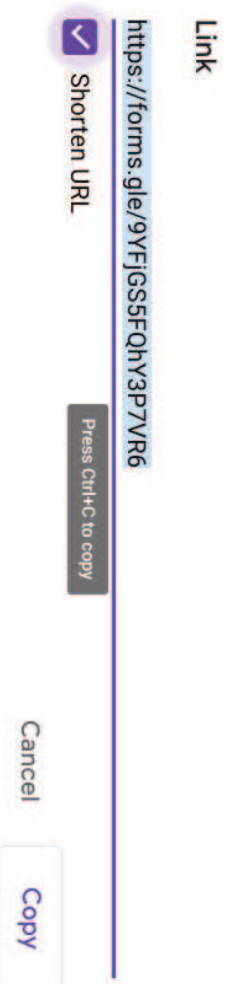
Select the "Send" button in the upper right corner to get a link to give to students.



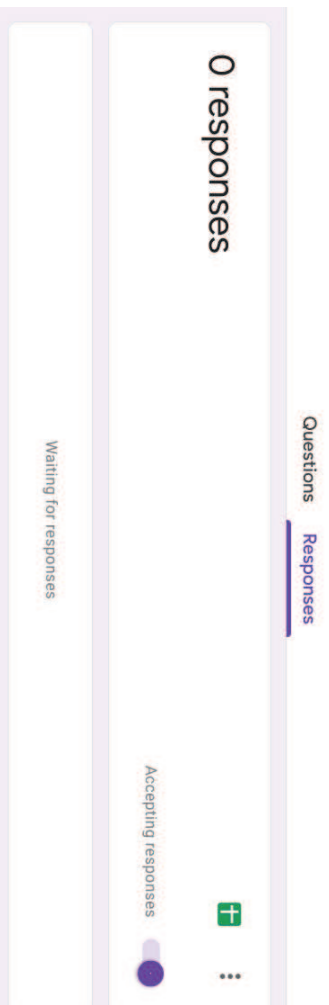
In the "Send via" panel, select the middle icon in order to choose to send the survey via a link.



Copy the link it provides you or select the "Shorten URL" box, then copy the link. This second option creates a link that will be easier for students to type.



Once people submit responses, they will show up in your Google Form under "Responses." Google will automatically provide you with some visualizations of these responses.



If you want to see the data in a spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when people respond to the survey.

For each survey, you will need to repeat the process above. You can choose to make a copy of the survey for each of your classes or choose to have one survey for all your classes.

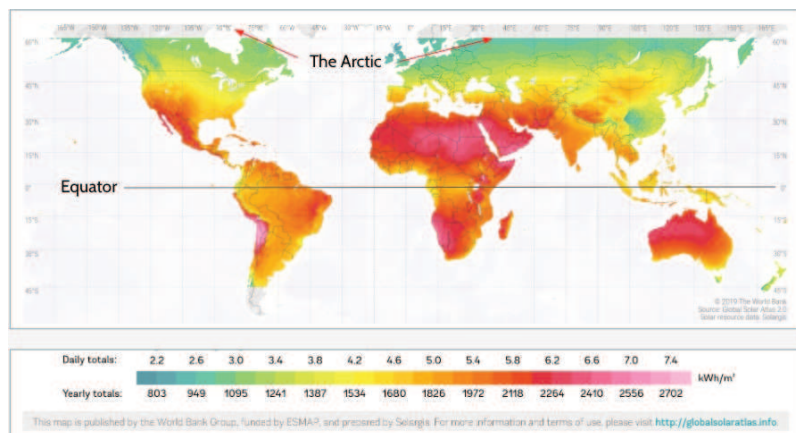
## Lesson 4: Answer Key

# L4 Electronic Exit Ticket Key

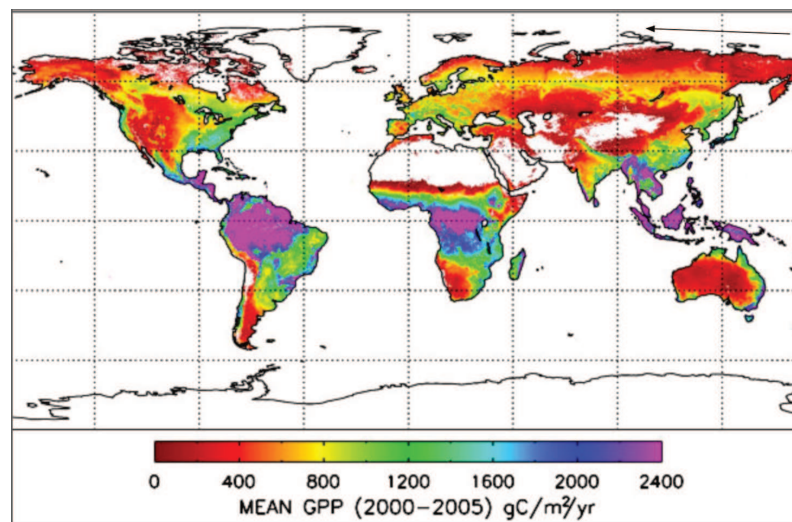
**4.A** Make a claim regarding changes in energy flow between the Sun and the Arctic and the potential of solar energy to be captured and stored in plants through photosynthesis. (SEP: 6.1; DCI: PS3.D.3; CCC: 5.2)

| Where these elements are addressed in this assessment. | 6.1 Constructing Explanations and Designing Solutions<br>Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. | PS3.D.3: Energy in Chemical Processes<br>The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. | 5.2 Energy and Matter<br>Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. |
|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Q1                                                     | X                                                                                                                                                                             | X                                                                                                                                                                        |                                                                                                                                                              |
| Q2                                                     |                                                                                                                                                                               | X                                                                                                                                                                        | X                                                                                                                                                            |
| Q3                                                     |                                                                                                                                                                               |                                                                                                                                                                          |                                                                                                                                                              |
| Q4                                                     | X                                                                                                                                                                             |                                                                                                                                                                          | X                                                                                                                                                            |
| Q5                                                     | X                                                                                                                                                                             |                                                                                                                                                                          |                                                                                                                                                              |
| Q6                                                     |                                                                                                                                                                               |                                                                                                                                                                          | X                                                                                                                                                            |

## Question 1



World Bank, CC BY-SA 4.0



MODIS GPP/NPP Project, NASA Earth Observation System

GPP = Gross primary productivity, which is a measure of photosynthesis.

Which of the following claims describes the relationship between solar radiation (independent variable) and photosynthesis (dependent variable) based on the images?

- A greater amount of solar radiation is associated with a lesser amount of photosynthesis.
- The amount of solar radiation does not matter; the amount of photosynthesis is always the same.
- A lesser amount of solar radiation is associated with a greater amount of photosynthesis.
- A greater amount of solar radiation is associated with a greater amount of photosynthesis.

**Correct response:**

- A greater amount of solar radiation is associated with a greater amount of photosynthesis.

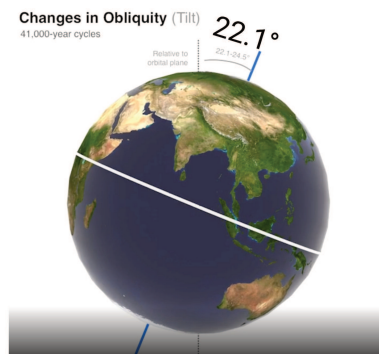
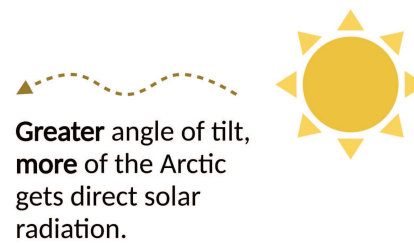
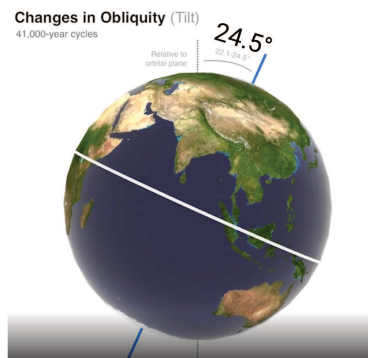
**Rationale for correct response:**

The amount of solar radiation changes based on latitude, with the greatest amounts concentrated near the equator and dropping off as you go toward the poles. There is also higher GPP, a measure of photosynthesis, in places where there is more solar radiation.

**What to do:**

Prompt students to review the relationships between the colors in the images and the variables. Then, have them use those relationships to review the claims and eliminate the claims not supported by evidence. In addition to revisiting the images in the question, point students to the reading to remind them of the relationship between the variables to help them choose the best claim.

## Question 2



Earth image source: <https://climate.nasa.gov/>

Illustrations created by OpenSciEd in BioRender



11,000 years ago, the Earth's tilt was greater than it is today. Which of the following best explains the relationship between the Earth's tilt and plant matter in the zombie fire system?

- The greater tilt caused more solar radiation in the Arctic, which led to more photosynthesis and more matter and energy stored in plants.
- The lesser tilt caused more solar radiation in the Arctic, which led to more photosynthesis and more matter and energy stored in plants.
- The greater tilt caused less solar radiation in the Arctic, which led to more photosynthesis and more matter and energy stored in plants.
- The greater tilt caused more solar radiation in the Arctic, which led to more photosynthesis and less matter and energy stored in plants.

**Correct response:**

- The greater tilt caused more solar radiation in the Arctic which led to more photosynthesis and more matter and energy stored in plants.

**Rationale:**

This question has students revisit the idea that the increase in solar radiation because of the Earth's tilt is the cause for the increase in the amount of solar energy available to the system, which causes an increase in the amount of matter produced by photosynthesis in the system.

**What to do:**

See Question 1.

### Question 3

Describe a time in your own life when you experienced an increase or decrease in solar radiation and how it impacted you.

**What to look for in response:**

*Accept all responses.* Validating these responses engages students in activating their **relevance** and **interest** in these issues, which can motivate future questions.

**What to do:**

Encourage students to consider changes in seasons, weather, vacations, and even day and night in their personal experience with solar energy.

### Question 4

Which of the following could help us generate evidence to help us make a claim that changes in solar radiation cause changes in photosynthesis?

- Carry out an investigation where we vary the amount of light and measure the amount of sugar produced through photosynthesis.
- Carry out an investigation where we vary the temperature and measure the amount of sugar produced through photosynthesis.
- Carry out an investigation where we vary the temperature and amount of light and measure the amount of sugar produced through photosynthesis.
- Carry out an investigation where we vary the amount of light and measure the amount of carbon dioxide produced through photosynthesis.

**Correct response:**

- Carry out an investigation where we vary the amount of light and measure the amount of sugar produced through photosynthesis.

**Rationale:**

Student claims should have been about the positive association between the amount of solar radiation and photosynthesis. Evidence could be generated to support this claim by varying the amount of light and measuring the amount of photosynthesis.

**What to do:**

Use student responses as you navigate into Lesson 5 and consider student ideas about the relationship between the variables and the kind of evidence necessary to support their claims. Adjust the time spent on reviewing this relationship based on these responses.

### Question 5

When choosing a claim, how did you use the dependent and independent variables to think about cause and effect?

**What to look for in response:** *Note: These could be different for each student.*

- Students should consider how the independent variable related to cause and the dependent variable relates to effect.

**What to do:**

Encourage students to think about which variable causes a change in the other variable (effect).

### Question 6

How did thinking about changes to the flow of energy and matter help you explain the lesson question: *How did so much plant energy and matter get into the peat in the zombie fire system?*

**What to look for in response:**

- Students should mention that the flow of energy is the source of the resources that the matter produced needs to make peat in the Arctic and that changes in the amount of energy available made it possible for there to be so much matter and energy in the peat.

**What to do:**

If students are having difficulty answering, you may want to separate “flow of energy and matter” to think about the two variables separately. Prompt them to think of the flow of energy to figure out where the energy is moving into and out of the system and then how matter is moving into and out of the system.

### Question 7

How have you collaborated with your peers to figure out science ideas over the course of the lesson?

**What to look for in response:**

- Student answers may vary.

**What to do:** Depending on student responses, it may be beneficial to revisit the Community Agreements.

- If many students do not have an example of how they collaborated with their peers, spend time revisiting the Community Agreements to ensure that students are using the agreements to make progress on figuring out science and engineering ideas.
- If students have trouble thinking about collaboration as a whole or their experience with the entire class, encourage them to think about how individual students have positively impacted their experience and helped them figure out science ideas using the Community Agreements in their interactions.

# Investigation Preparation

## Earth's Tilt Investigation with Elodea and BTB

### Safety:

- Wear indirect vented chemical splash goggles, a non-latex apron, and nitrile gloves during the setup, hands on, and takedown segments of the activity.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Use caution when working with glassware, which can shatter if dropped and cut skin.
- Use caution when working with clamp lights - use only a GFCI protected electrical receptacle to power the lights and keep away from water sources.
- Also, use caution when touching the light so as to prevent burning of the skin.
- Immediately wipe up any spilled water off the floor to prevent slip/fall hazards.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.

**Three or four days before the investigation**, make sure you have all materials needed for this investigation. This is what is needed for each group of 4-5 students:

1. One-two standard sprigs of Elodea that can be cut into equally sized pieces to fit into three 50 mL test tubes. Follow vendor instructions to ensure plants will be alive when students will use them for this investigation.
2. Three 50 mL test tubes with airtight lids labeled A-C.
3. 200 mL of BTB solution.



You will also need:

1. At least three lamps with full UV spectrum bulbs that are safe to leave on overnight.
2. If the laboratory lamps include clamps, you will need ring stands to attach the lamps.

The BTB solution should be prepared 3-4 days in advance because it needs to be a carbon dioxide-induced BTB solution. BTB is most commonly sold as a stock solution of 0.04% aqueous BTB. This stock solution can be used to create the BTB solution needed in this investigation:

1. Use a 1:100 mL dilution of BTB stock solution and distilled water. For a class of 35 students with 7 groups of 5 students each, you will need to make 1500 mL of the BTB solution; dilute 15 mL of the stock 0.04% aqueous BTB into 1485 mL of distilled water.

2. The color of this BTB solution when initially mixed should be a light blue. The solution needs to be yellow (exposed to carbon dioxide) before students use it in their investigation. This is because students need to see if plants are photosynthesizing and absorbing carbon dioxide, which will change the yellow-colored BTB solution to a blue-colored BTB solution during their investigation. You can try to achieve this yellow color by leaving the BTB solution out and uncovered for a few days; the carbon dioxide in the air should change the solution to a yellow color. This however is heavily influenced by the environment the solution is left in.

If you have issues getting this yellow color or preparing this solution on the day of the experiment, a quick way to change the BTB solution from blue to yellow is to get a straw and blow bubbles into it. The carbon dioxide from your breath will quickly change the color to yellow. **Be sure to not drink any BTB solution by mistake if you do this.**

**On day 1 of the investigation**, ensure each group has the materials they need. At the end of the students' investigation setup, make sure students put their group name on their test tubes to keep track of which tubes are from which group. Students should make sure that the lids are tight on the test tubes.

The test tubes should be set up as follows:

| Placement   |                                                                                                                   |                                                                                      |
|-------------|-------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Test Tube A | Indirect light                                                                                                    |  |
| Test Tube B | Direct light                                                                                                      |   |
| Test Tube C | Covered in aluminium foil. Half the groups should put it under direct light, the other half under indirect light. |                                                                                      |

**On day 2 of the investigation**, groups should find the test tubes they put under the lights.

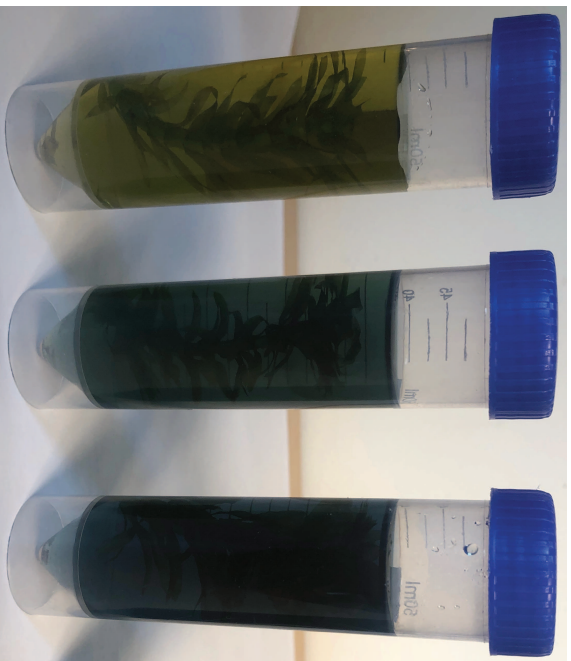
If you conduct the starch demonstration yourself rather than using the photos, make sure you save a test tube from each condition.

## Energy and Matter Storage in Plants (Day 3: Optional)

**Three or four days before the investigation,** make sure you have all materials needed for this investigation including samples from the student investigation *Earth's Tilt Investigation with Elodea and BTB*.

- Petri dish or other leak proof shallow container
- Scissors or forceps
- Reagent grade iodine solution, 30 mL
- Pipette
- Hot plate
- Heat-proof tweezers/forceps
- Heat-proof tongs
- Ethanol 95% laboratory grade
- Heat-proof 1000 ml beaker
- Heat-proof 250 mL glass flask
- Safety goggles
- Non-latex apron
- Nitrile gloves

Add approximately 500 mL of water to a 1000 mL beaker. Place the beaker on the hot plate and set it to boil.



Ask students to take a single leaf clipping from the plant that was exposed to direct light. Collect all the clippings and add to the water once it is boiling. The leaves should stay in the boiling water for approximately 60 seconds and then removed using heat proof tweezers or forceps.



Remove the leaves from the boiling water and place in a Petri dish.



Add approximately 100 mL of ethanol to a 250 mL heat proof flask. Using the tongs, submerge the flask in the beaker of boiling water until the ethanol boils.



Once the ethanol is boiling use the heat proof forceps to add the leaves to the ethanol in the flask for 1-2 minutes.





You should see the water turn slightly green as the chlorophyll is extracted from the leaves.



Remove the leaves from the flask and place them in the Petri dish or shallow container. Adding a white background (piece of paper) will help students see the color change when the iodine is added.



Use the pipet to add a drop of iodine solution to the clippings.



Repeat for clippings kept in the dark.

## Lesson 6 Teacher Reference

# Discussion-Mapping Tool

### Instructions

1. Print one copy of the second page of this tool for each class section.
2. Add students' names to the circle in the order that students are sitting. You may want to do this ahead of time and then ask students to sit according to the map. Include a landmark, like your desk or the whiteboard, on the image to help orient yourself on the map.
3. Write the question that students are trying to answer at the top of the page.
4. Select a student recorder who will map the discussion as it happens. Decide ahead of time if you will have multiple students take turns mapping and when you will move the map to a new student recorder.
5. If this is the first time you are using a discussion map, explain to students that each time someone speaks, the recorder will draw a line from the previous speaker to the new speaker's name. You may want to mark where the conversation begins and ends, but the goal is to map the overall conversation patterns rather than to be able to retrace the entire conversation.
6. Once the discussion begins, allow students to take the lead on moving the discussion forward. Sit in the circle as a participant rather than standing in front of the class as a facilitator. This will allow students to practice building on each other's ideas directly.
7. Be mindful of group dynamics, especially when displaying the map and discussing patterns of contributions. Avoid focusing on the contributions of single students, and instead redirect the class to notice class-level patterns.

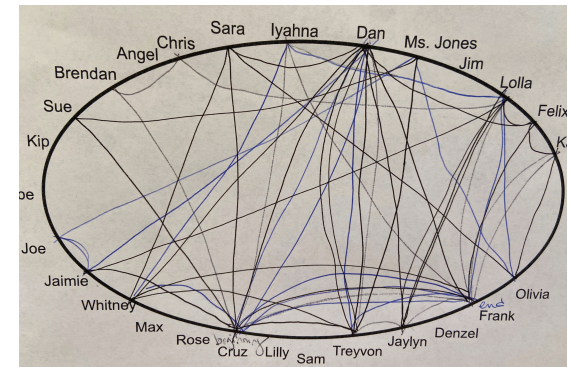
An example of a completed discussion map is pictured here:

### Discussion-Mapping Codes

The key at the bottom of the discussion map contains codes that can be used to label the types of student contributions. The first few times that you create a discussion map with your students, you should focus only on recording the flow of the conversation. This allows students to get comfortable with the process. Once students have experience recording and interpreting those initial patterns, you can add discussion-mapping codes to future discussion maps. There is an extra column where you can add your own discussion codes as needed based on individual class needs and agreements. You may also choose to just use some of the discussion codes based on the type of discussion that your students are having. In this case, be sure to cross out the codes that you are not using so that student recorders know not to include them.

### Key Ideas

There is space to list up to three key ideas that emerge from the discussion on the tool itself so that the class can keep track of the ideas that are raised in the discussion. If you choose to use codes to annotate student contributions, you can also use the codes 1, 2, and 3 to map when those ideas are talked about.

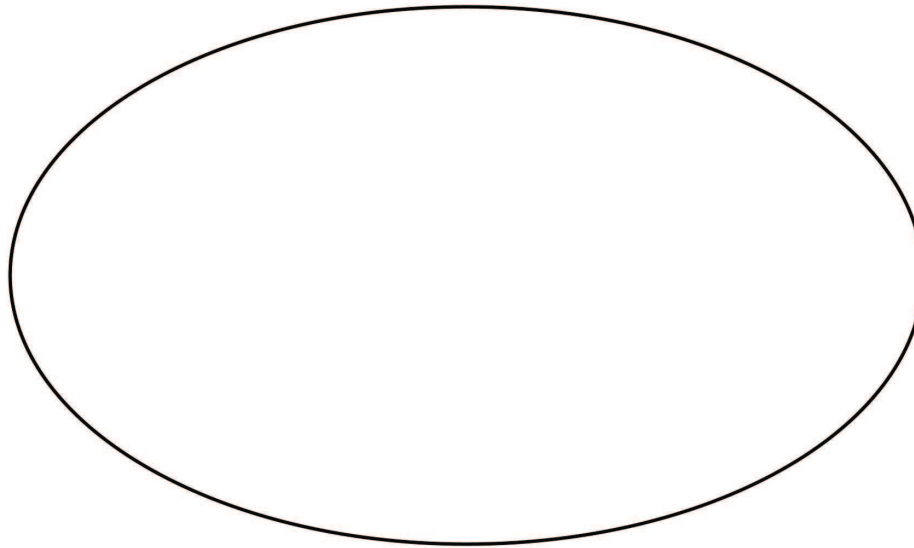


Question we are trying to answer:

Date: \_\_\_\_\_

L#: \_\_\_\_\_

Period: \_\_\_\_\_



Key Ideas

| Discussion Codes (Choose up to 3) |                            |                            |                                |                        |
|-----------------------------------|----------------------------|----------------------------|--------------------------------|------------------------|
| <b>C</b> - claim given            | <b>CL</b> - clarified idea | <b>?</b> - asked question  | <b>T</b> - tied ideas together | <b>I</b> - interrupted |
| <b>E</b> - gave evidence          | <b>A</b> - affirmed/agreed | <b>NI</b> - new idea added | <b>RP</b> - related phenomena  |                        |
| <b>OT</b> - off topic             | <b>D</b> - disagreed       | <b>R</b> - repeated idea   | <b>--</b> idea ended           |                        |

# Zombie Fire Explanation Feedback Guidance

**6.B** Construct an explanation based on evidence about how **photosynthesis** and **cellular respiration** change **energy** and **matter** in the **biosphere**, **geosphere**, and **atmosphere** and predict what might happen in the future. (SEP: 6.2; DCI: LS.2.B.3; CCC: 5.2)

| 3D Elements Addressed in This Assessment |                                                                                                                                                                                                                                                                                                                                                                       |
|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SEP</b>                               | Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (SEP: 6.2) |
| <b>DCI</b>                               | Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, <del>oceans</del> and geosphere through chemical, physical, geological, and biological processes. (DCI: LS.2.B.3)                                                                                                 |
| <b>DCI</b>                               | Used earlier in the lesson and previous lessons, and students may draw on it here.                                                                                                                                                                                                                                                                                    |
|                                          | As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (DCI: HS.LS1.C.3)                                                                                                                                                                                 |
| <b>CCC</b>                               | Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (CCC: 5.2)                                                                                                                                                                                                                        |

To study changing fires in the Arctic, scientists took pictures of fires from space, using special cameras. The first image (top-left), acquired in September 2015, shows the burn scar from the Soda Creek Fire, which scorched nearly 17,000 acres in southwest Alaska near the Kuskokwim River. The fire was never completely extinguished before winter set in. In April 2016 (top-right), the fire continued to smolder in the peat under a layer of snow. When the snow finally melted in late May (bottom-left), the additional heat and oxygen caused flames to re-emerge and quickly spread.

**Instructions:** Use evidence from your investigations to explain:

**A) How was there enough matter and energy in the zombie fire system for a zombie fire to burn under ice?**

**B) What will happen in the future if temperatures continue to rise?**

- Make explicit connections between the past and future of zombie fires or related phenomena.
- Use the space below to jot down some notes. Then write or draw your explanation on the next page.
- Use your Gotta-Have-It Checklist, *Fires Progress Tracker*, and science notebook.

|             | Foundational Pieces                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Linked Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Organized Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3D Elements | <p>In this explanation, look for:</p> <p>Students state a claim that the matter and energy are changing in the peat/permafrost system during zombie fires. Peat is fuel for zombie fires because it has matter and energy, especially when the permafrost thaws due to heat and bringing more oxygen into the system. If temperatures continue to rise, there will be more zombie fires.</p> <p>OR</p> <p>Students reference evidence from the Decomposition Investigation or the Earth's tilt investigation but may reason about yeast and aquatic plants without connecting them to the zombie fire system.</p> | <p>In this explanation, look for:</p> <p>Students' claims address the effects of temperature on the flow of matter and energy in the peat system, and that more energy and matter stay in the peat. Peat is fuel for zombie fires because it has matter and energy, especially when the permafrost thaws due to heat and bringing more oxygen into the system. If temperatures continue to rise, there will be more peat fires and less peat.</p> <p>Students do not connect it to the rate of decomposition or photosynthesis.</p> <p>AND</p> <p>Students reference evidence from the Decomposition Investigation and Earth's tilt investigation and link them to the zombie fire system without connecting it to the rate of decomposition in the peat, or photosynthesis in the plants to the amount of energy and matter available for burning.</p> | <p>In this explanation, look for:</p> <p>Students' claims address the rate of decomposition/cellular respiration as low when it is cold and therefore the flow of energy and matter is reduced. At cold temperatures, the rate of energy transfer from the peat to the atmosphere is reduced. Peat is fuel for zombie fires that contains large amounts of energy stored in carbon-based molecules, especially when the permafrost thaws due to heat and bringing more oxygen into the system through holes in the permafrost. If temperatures continue to rise and peat is further exposed to oxygen from thawing, the peat carbon sink will decrease, and there will be more fires.</p> <p>Solar radiation for photosynthesis is needed to capture light energy and convert it to chemical energy and matter for the plant. Changes in the Earth's tilt allowed for more matter and energy to be stored in plants, which later became peat.</p> <p>Evidence includes rate of decomposition from the Decomposition Investigation and scientist's study of oxygen and decomposition rates, rate of photosynthesis in Earth's tilt investigation, and starch test.</p> |

| Example | <p>The energy and matter stay in the peat until it burns like it did in the cold decomposition investigation with yeast where the carbon dioxide stayed in the sugar.</p> <p>The plants took in more carbon dioxide with more light. The water turned more yellow.</p> <p>In the future, it will get hotter with more decomposition/burnin g.</p> | <p>The energy and matter got into the peat a long time ago when there was more light and have stayed in the peat. It is cold in the peat/permafrost.</p> <p>The plants got all the matter and energy from the Sun. In the plant investigation, the most matter was converted from carbon dioxide to plants when the light was direct.</p> <p>The yeast did not make carbon dioxide when it was cold.</p> | <p>The plants got all the matter and energy from the Sun. In our investigation of the Earth's tilt, we found that most matter was converted from carbon dioxide to plants when the light was direct. There is so much peat in the permafrost because there was more photosynthesis in Earth's past when there was more direct solar radiation in Earth's history when the tilt of the Earth was different. When all of the plants died, they became peat.</p> <p>The energy and matter stay in the peat because the rate of decomposition was low when the peat formed under low oxygen condition. Then it got frozen, which made the decomposition even slower. Evidence from our decomposition investigation shows that cellular respiration/decomposition is slower in the cold. Scientists' investigations showed evidence of slow decomposition when peat formed under water with low oxygen.</p> <p>If the air temperature continues to rise, there will be more melting. The peat will be exposed to more oxygen from the air. Higher temps and more oxygen will speed up the rate of cellular respiration in the peat, more carbon dioxide will go to the atmosphere, and peat will be a fuel. The heat and oxygen make it more likely to burn.</p> |
|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Feedback/<br>What to do           | <p><i>To revise toward linking:</i><br/>Instruct students to integrate evidence about matter and energy (from earlier investigations such as the yeast lab or starch test) into their explanations. Ask, <i>What happens with the matter and energy at each part of the system?</i></p> <p>Ask, <i>How is peat connected to photosynthesis OR peat connected to decomposition?</i></p>                                                                                 | <p><i>To revise toward organizing:</i><br/>Encourage students to draw on additional evidence, either from the images included in the assessment or from our own investigations with the peat/permafrost.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <p><i>To extend:</i><br/>Focus students not only on thinking about how they can explain what is happening in the past and future in the zombie fire system but also on making predictions about what will happen over the next several hundred years beyond additional carbon dioxide in the atmosphere. Point them to the visual inquiry to emphasize what the larger-scale effects might be.</p>                                  |
| Suggestions<br>for<br>Instruction | <p><i>Linking:</i><br/>If the majority of the class demonstrates a foundational understanding, revisit the class model for the peat/permafrost system during zombie fires and ask students to consider how the flow of matter and energy changed at different places and scales.</p> <p>Ask students to explain what must be happening in the smaller-scale processes within plants or decomposers.</p> <p>Ask students to revise their explanations after review.</p> | <p><i>Organizing:</i><br/>If the majority of the class demonstrates a linked understanding, ask students to work with a partner to discuss the images in the assessment and figure out how they support their explanations.</p> <p>Ask partners to review how decomposition rates affect the flow of matter and energy in both the banana and yeast system models.</p> <p>Ask partners to review how the tilt of the Earth can affect the amount of solar radiation available for photosynthesis.</p> <p>Support students in seeing how all of the investigations are models of the peat/permafrost system.</p> <p>Then bring the class together to discuss their ideas and review some of the investigations we have done and how they relate. Have them rewrite their explanations afterward with additional evidence.</p> | <p><i>Extending:</i><br/>If the majority of the class demonstrates an organized understanding, challenge students by asking them to think about solutions that might change the balance of energy inputs and outputs in Earth's biosphere.</p> <p>Ask students to imagine another model or phenomenon that functions like the peat/permafrost system.</p> <p>Ask students to predict how matter and energy flow in that system.</p> |

**Explanation Self-Check:** Use the checklist below to interpret your own performance on your explanation. If needed, add to your explanation based on what you were missing in the checklist below.

| Check ? | Attribute                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|---------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|         | Did I include valid and reliable evidence obtained from a variety of sources (such as models, investigations, simulations, etc.) to support my explanation?<br>Investigations with possible evidence: <ul style="list-style-type: none"><li>• Burning Fuel Samples data table in science notebook</li><li>• <i>Peat, Permafrost, Carbon</i></li><li>• <i>Optional: Banana Investigation</i></li><li>• <i>Decomposition Investigation Data and Sensemaking</i></li><li>• <i>Geologic Time</i></li><li>• <i>Tilt: Making Sense</i></li><li>• Starch test</li></ul> |
|         | Did I make a claim that included the changes happening for both matter and energy into, out of, and within the system?                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|         | Did I explain the interactions between components?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|         | Did I describe the mechanisms that explain each interaction?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|         | Did I use evidence of the past and present to predict the future?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

**Social and Emotional Learning: Check, Reflect, Connect**

1. **Check.** How do you feel about what we are learning in this unit at this time? You may use the feelings wheel above to help you identify your feelings.
2. **Reflect.** Use the box below to describe those feelings and their intensity using words and/or pictures.
3. **Connect.** If you would like to talk with a trusted adult about your feelings, tear off this sheet and use it as a conversation starter.

Accept all responses.



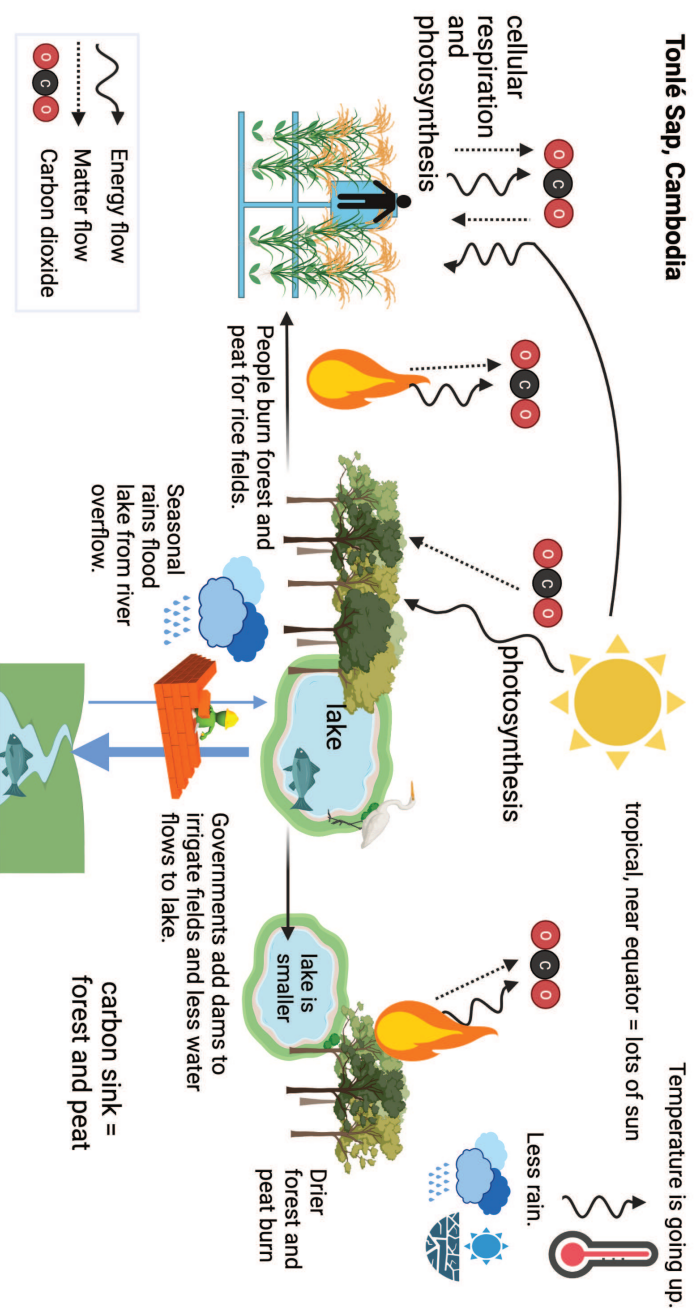


## Lesson 7 Teacher Reference

# Sample Models

Examples of the group models for each case study. Note these demonstrate only one possible representation of each case study.

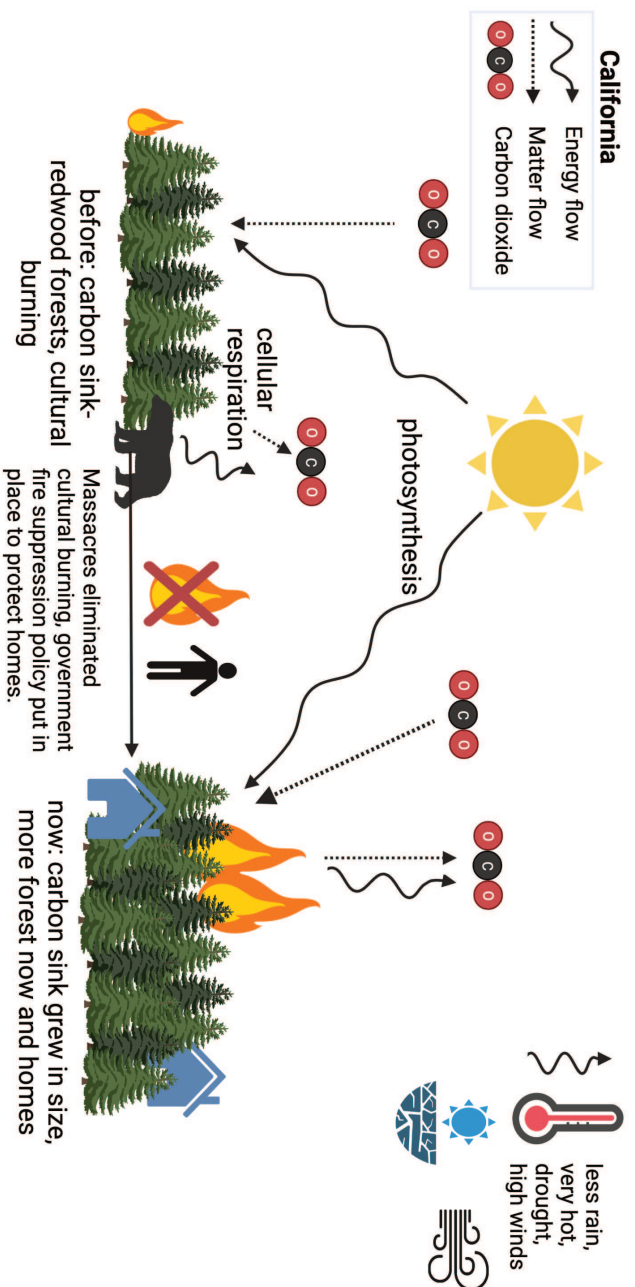
Why is Tonlé Sap, Cambodia's carbon sink likely to burn?



Trees and plants are made of carbon and energy from photosynthesis. Carbon in peat and trees is a carbon sink. The river water is dammed and diverted for rice irrigation, which is drying out peat in the lake. Dry peat exposes more of the carbon sink, which is available to burn. People burn to make space for more rice farms. Burning releases energy and carbon dioxide. The sun is making everything hot and drying out the remaining forest, making it more likely to burn.

Illustrations created by OpenSciEd in BioRender

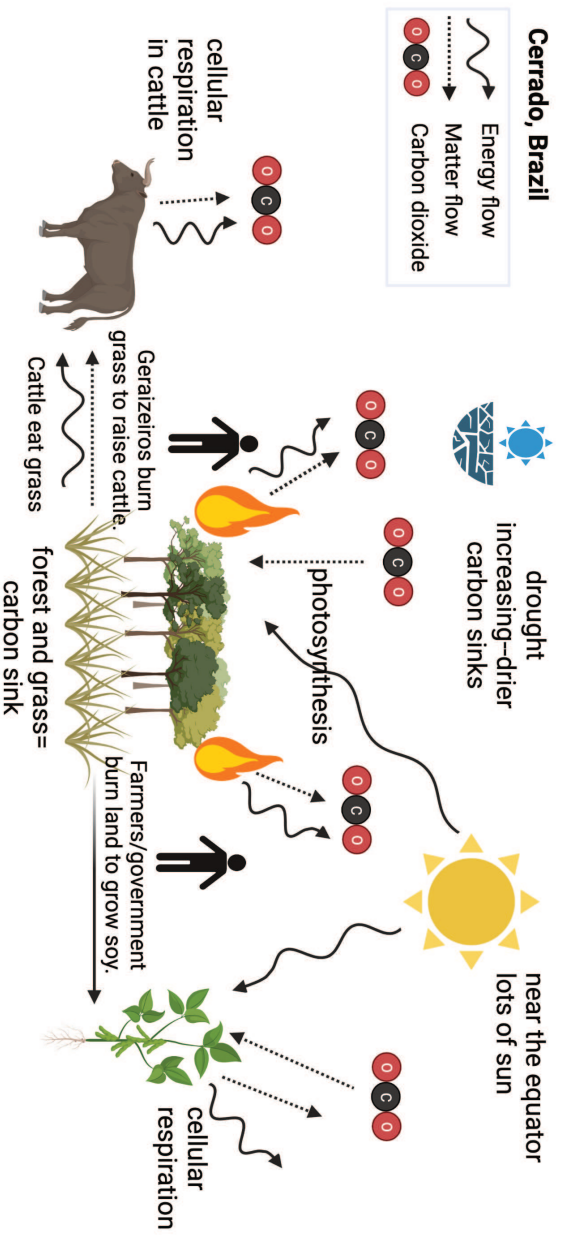
## Why is California's carbon sink likely to burn?



The redwood forest is the carbon sink. The carbon and energy was transferred to the trees and the redwood forest by photosynthesis. Drought and rising temperatures dry out the soil, grasses, and trees, which makes them highly likely to burn. The carbon sink is bigger today because of fire suppression policies and drier conditions. People live in carbon sink (surrounded by trees) so fire suppression does not allow for thinning out biomass which would reduce fire intensity.

Illustrations created by OpenSciEd in BioRender

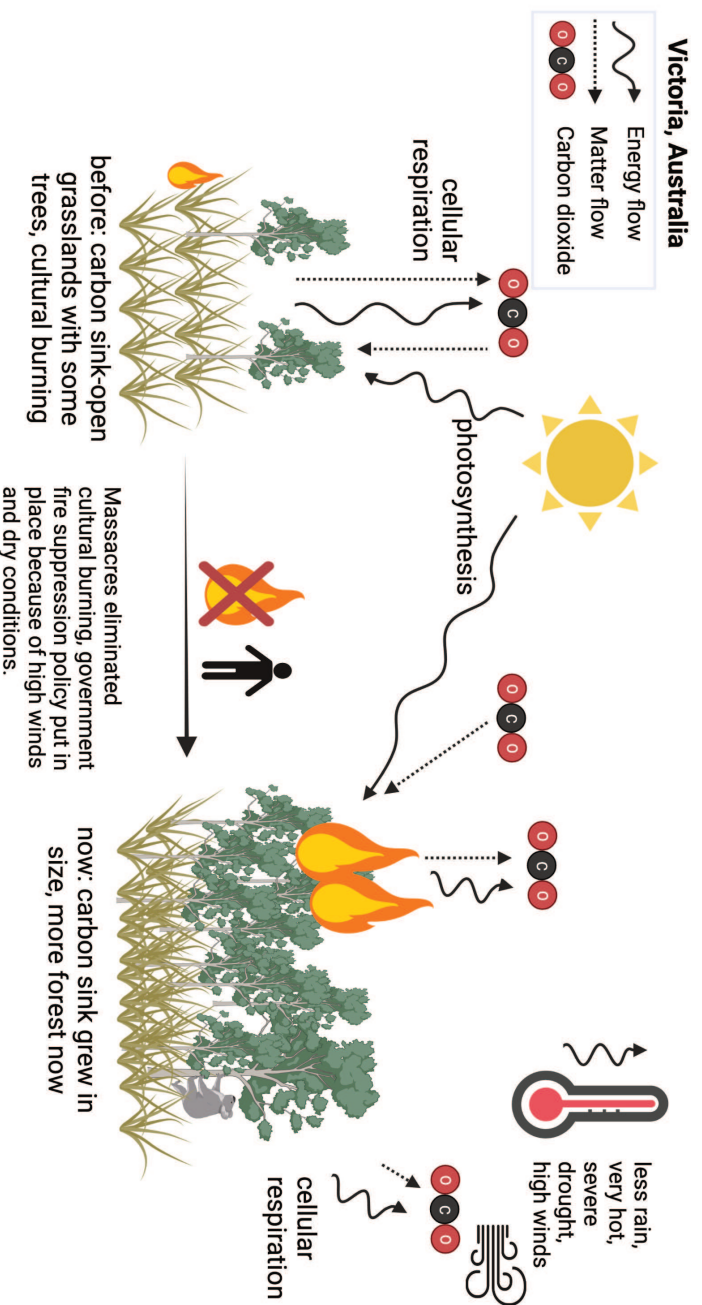
## Why is the Brazilian Cerrado's carbon sink likely to burn?



Drought makes the dry season even drier, which makes the Cerrado grass and trees (carbon sink, which store carbon and energy from photosynthesis) even more flammable. Humans burn the trees and grass to clear it for soy and cattle, reducing the size of the carbon sink. Fires get really big and burn large areas, releasing carbon dioxide and energy.

Fire suppression policies stop even small natural fires, so a larger part of the carbon sink is available to burn.

Illustrations created by OpenSciEd in BioRender

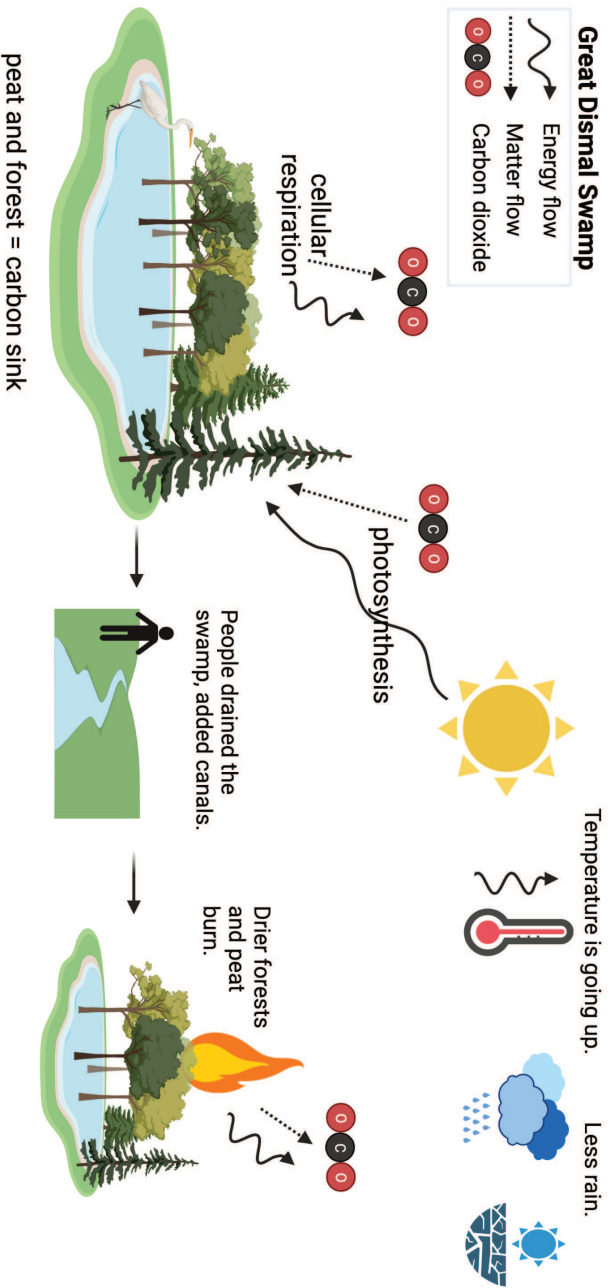


The carbon sink is grass and eucalyptus forest. Photosynthesis transferred energy and carbon into the plants to create the sink. Today, very dry grasses and less rain makes carbon sink highly flammable. Bans on cultural burning, fire suppression that would have thinned out grasses and wood does not happen anymore making big, intense fires very likely.

Illustrations created by OpenSciEd in BioRender



## Why is The Great Dismal Swamps carbon sink likely to burn?



Trees and plants are made of carbon and energy from photosynthesis. Carbon in peat and trees is a carbon sink. People drained the swamp so they could get timber and build railroads and canals. Dry peat is more available to burn and release energy. The temperature is going up, there is less rain, drying out the remaining forest and peat, making it more likely to burn. Burning releases energy as heat and light, carbon released as carbon dioxide.

Illustrations created by OpenSciEd in BioRender



# Making Sense Key

**Please note:** This document shows sample student responses to some of the questions on *Making Sense of Case Studies*. Note that this is not an exhaustive list of responses to these questions, just initial ideas. Students may not generate all of these ideas on their own, or they may generate additional ideas beyond the ones listed here. The key ideas shown here are suggestions for important ideas the students could include. It is important, however, to appropriate the words and ideas that your students use and agree upon during discussion and in their writing. Your class's ideas could be articulated differently and may include other ideas not listed here. Actively look for different ways students share and represent their ideas as an opportunity to communicate to your students that different ways of representing our thinking are valuable, such as in words, pictures, speech, and movement.

## Making Sense

1. List some of the critical participants (human and nonhuman) in this case study.

Indigenous groups that live in the area, national governments, timber and railroad companies, farmers, ranchers, animals and plants, etc.

2. What historical events occurred that shape how or why fires occur in this place? Who made key decisions and why?

Colonizers killed Indigenous people who conducted cultural burns. Denser forests grew in their place, creating more fuel that can burn. Companies drained the swamp, and governments dammed rivers so water does not back up into the lake; therefore peat dries out and is easier to burn. Government programs encouraged converting natural areas to agricultural fields and people burn the fields, but they get out of control.

3. What makes the energy and matter in this carbon sink more likely to burn now?

Fire suppression: Small fires return the carbon dioxide and energy to the atmosphere. When these fires no longer occur, organic matter sits in the ecosystem and becomes fuel for fire.

Drought: Lack of rainfall over time means that there is less moisture in the environment, so everything is dry and flammable.

Increased temperature: As the ecosystem becomes warmer, the more dry the environment becomes. These really hot days can sometimes make small sparks become big fires.

Land use changes: The dams on the Tonlé Sap were moving water from the lake, so the water was not flooding the area to keep the peat moist, and it dries out more and more every year. The Cerrado is being burned for soy and cattle farms, so the forest is not being replanted. In California, homes are being built in the forest. The Great Dismal Swamp was drained for railroads and timber.

4. How did the carbon sink originally form? Be sure to explain how and where carbon and energy flows into this system.

Carbon dioxide, water, and sunlight get used in photosynthesis by the plants. They rearrange atoms from carbon dioxide and water into sugars and store some carbon and energy in bigger molecules like starch. Carbon and energy are stored in the body of plants and trees in the hydrocarbons.

Animals or decomposers normally eat the organic matter and put some of the carbon back into the atmosphere as carbon dioxide, but in swamps and flooded areas, there is less oxygen so peat forms. Peat is a big energy sink.

5. What wonderings do you have about these places, lands, and waters?

Accept all responses. Sample questions include:

Why do cattle ranchers and other farmers burn their fields?

How does cultural burning help with hunting?

Which releases more carbon dioxide, lots of little cultural burns or one big fire?

Why do China and Laos get control over water that flows through Cambodia?



Why do people move into areas where the woods might burn?

6. What initial ideas do you have about what might be done to better protect this carbon sink from burning?

Could we bring back cultural burning?

Could we stop people from moving into the forests so we can stop suppression policies?

Could we stop building dams and canals and keep the peat wet?

Lesson 8: Answer Key

# CO2 Investigation Responses

Before the Investigation

1. Add your directional hypothesis here.

Student responses may vary.

An increase in carbon dioxide will cause an increase in temperature in the bottle compared to the bottle without the added carbon dioxide.

2. What is the independent variable?

The independent variable is the presence/absence of additional carbon dioxide in the bottle system.

3. What is the dependent variable?

The dependent variable is the temperature of the air inside the bottle system.

During the Investigation

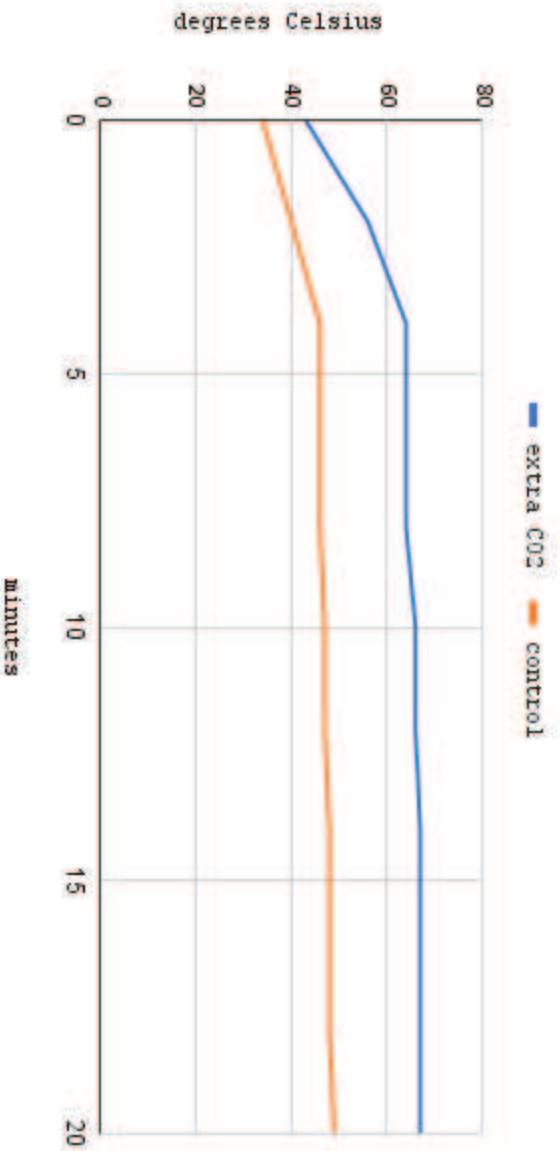
Record the air temperature (°C) in each bottle at 2-minute intervals for 20 minutes. Record your results in the table below and include a title for the table.

Title: Temperature over time in the bottle system.

|            | System with Increased CO <sub>2</sub> | Control System |
|------------|---------------------------------------|----------------|
| 0 minutes  | 43                                    | 34             |
| 2 minutes  | 56                                    | 40             |
| 4 minutes  | 64                                    | 46             |
| 6 minutes  | 64                                    | 46             |
| 8 minutes  | 64                                    | 46             |
| 10 minutes | 66                                    | 47             |
| 12 minutes | 66                                    | 47             |
| 14 minutes | 67                                    | 48             |
| 16 minutes | 67                                    | 48             |
| 18 minutes | 67                                    | 48             |
| 20 minutes | 67                                    | 49             |

Make a graph of your data here.

## Relationship between carbon dioxide and temperature



### After the Investigation

#### Making sense:

1. Does the evidence support or refute your hypothesis?

#### Support

2. Use evidence to explain the relationship between the independent and dependent variables in this experiment.

The temperature of the air inside the bottle without Alka-Seltzer (control) increased on average by 2°C per minute. The air temperature in the bottle with the Alka-Seltzer tablets (increased CO<sub>2</sub>) increased by larger amounts before leveling off at around 10 minutes. Increasing the carbon dioxide in the bottle caused an increase in temperature over 20°C.

3. Based on evidence from the bottle system, Based on evidence from the bottle system, explain the effect of increased carbon dioxide on one of the ecosystems you investigated in Lesson 7.

The fires are putting more carbon dioxide into the atmosphere, which makes it hotter. The effects of it getting hotter could be (student responses may vary): more fires because it is drier, fewer plants because the heat makes the water dry up.

## Lesson 9: Answer Key 1

# Carbon/Energy Quantitative Model Key

### Making Sense

1. Record the information below from your carbon atom's journey either in the tables below or on your spreadsheet and then add it to the class data.

| System           | Total | Matter         | Total | Energy                                                                 | Total |
|------------------|-------|----------------|-------|------------------------------------------------------------------------|-------|
| Atmosphere       | 6     | Carbon dioxide | 6     | Energy remains in the same arrangement of atoms.                       | 3     |
| Hydrosphere      | 0     | Food fuel      | 0     |                                                                        |       |
| Human activity   | 0     | Biomass        | 4     | Energy flows to another place/system in the same arrangement of atoms. | 0     |
| Bio: producers   | 4     | Fossil fuel    | 0     |                                                                        |       |
| Bio: herbivores  | 0     | Waste          | 0     | Energy changes result from the atoms rearranging.                      | 0     |
| Bio: omnivores   | 0     | Sediment       | 0     |                                                                        |       |
| Geo: soil & rock | 0     | Material good  | 0     | Energy flows to another place/new system AND the atoms are rearranged. | 2     |

2. Why did all the carbon start out in the atmosphere?

Because we were using the model to explain the effects of added carbon dioxide to the atmosphere due to fire.

3. What relationship and/or patterns do you notice about your carbon atom's journey based on the data in the table?

My carbon spent most of the time in the atmosphere as carbon dioxide and either remained in the same arrangement of atoms or went to a new place and rearranged.

4. Write and/or draw a brief story in words and/or images from your carbon atom's point of view that describes the journey it just took through the Earth's spheres. Make sure to include the system, what happened, and where it went next. Choose specific members of the system (for example: say zebra, not herbivore). Be creative!

I floated around in the atmosphere for many years (rolls) before I got close enough to an oak tree that used energy from the Sun and water to combine me with some other atoms to form glucose and then part of an acorn. I fell to the ground and stayed there for a while until a squirrel came along and ate me to get some energy from the starches stored in the carbon-based atoms inside the acorn. That squirrel was a messy eater! The

squirrel was being chased by a hawk, but it used some of the energy stored in the carbon-based molecules I was in to do cellular respiration to run quickly and get away. I was transferred to a carbon dioxide molecule and floated back up into the atmosphere, where I floated around for a few more years.

Stories should contain:

- all 10 locations
- references to different carbon-based molecules
- references to transfer of energy
- references to mechanism of change
- identification of some of the generic items on the cards as specific items in the story (for example: naming an oak tree instead of a producer, or gasoline in a car instead of a fossil fuel)

5. Compare your results with other students. While each of your journeys was different, was there anything similar about them?

Answers will vary, but most students will see that carbon dioxide spent the most time in the atmosphere and biosphere.

6. How does this quantitative model help us understand the relationship between fires and global increases in carbon dioxide and temperature? **NOTE: Student answers here help prepare them to answer the navigation question on slide L.**

The carbon that gets added to the atmosphere spends most of its time there, which will make the atmosphere hotter. It also moved into the biosphere. We know the biosphere can store a lot of carbon in carbon sinks, and when it is hotter, they are more vulnerable to burning, so staying in the biosphere might make fires worse because there will be more fuel.

## Lesson 9: Answer Key 2

# Electronic Exit Ticket Key

This Electronic Exit Ticket addresses 3D elements associated with a lesson-level performance expectation from Lesson 9. This assessment is designed to make it easy to gather information about where your students are still struggling to put the pieces together.

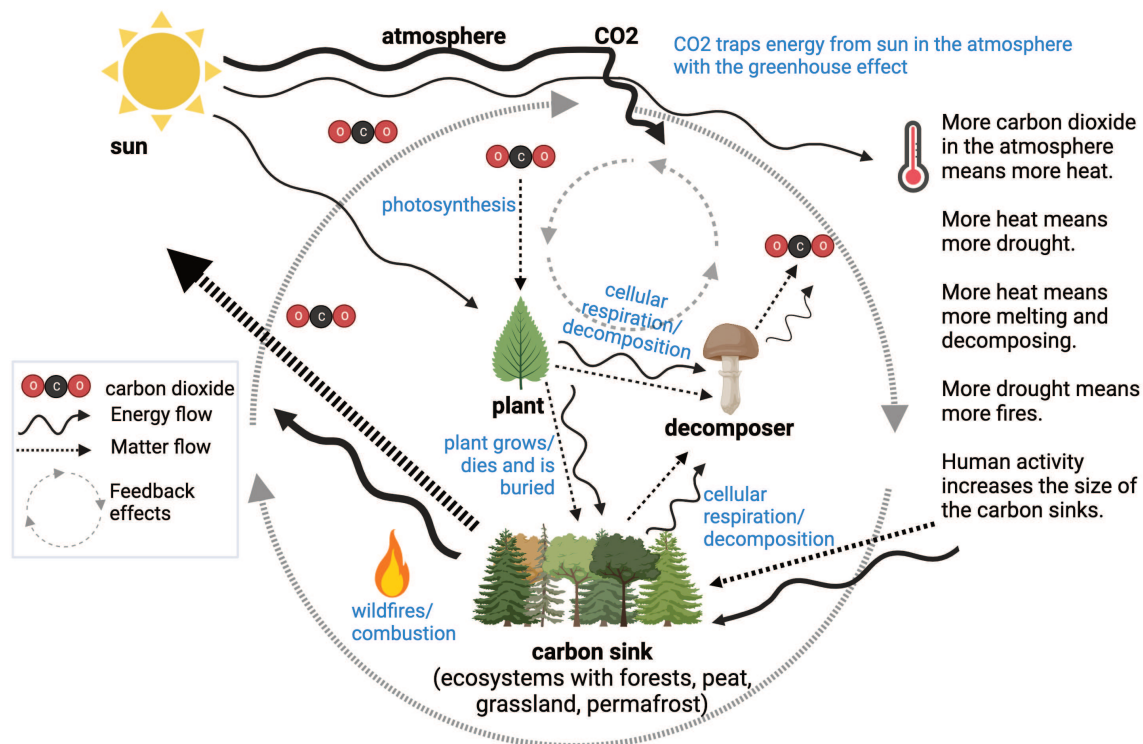
The relevant lesson-level performance expectations is:

**9.B Develop a model to explain** how **energy from the Sun** and wildfires **drives the cycling of carbon, leading to a rise in carbon dioxide concentrations and atmospheric temperatures.** (SEP: 2.3; DCI: ESS 2.D.3; CCC: 5.4)

The elements of this lesson-level performance expectation assessed in this exit ticket are:

| 3D Elements Addressed in the Assessment                |                                                                                                                                                                                             |                                                                                                                                                        |                                                                                          |
|--------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Where these elements are addressed in this assessment. | 2.3. Developing and Using Models<br>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. | ESS2.D.3: Weather and Climate<br>Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. | 5.4 Energy and Matter<br>Energy drives the cycling of matter within and between systems. |
| Q1                                                     | X                                                                                                                                                                                           | X                                                                                                                                                      |                                                                                          |
| Q2                                                     |                                                                                                                                                                                             | X                                                                                                                                                      | X                                                                                        |
| Q3                                                     |                                                                                                                                                                                             |                                                                                                                                                        |                                                                                          |
| Q4                                                     | X                                                                                                                                                                                           |                                                                                                                                                        | X                                                                                        |
| Q5                                                     | X                                                                                                                                                                                           |                                                                                                                                                        |                                                                                          |
| Q6                                                     |                                                                                                                                                                                             |                                                                                                                                                        | X                                                                                        |
| Q7                                                     |                                                                                                                                                                                             |                                                                                                                                                        |                                                                                          |

## Question 1



Illustrations created by OpenSciEd in BioRender

Use the [model of Earth's systems](#) (specifically the biosphere and atmosphere subsystems) above to predict what would happen to [global atmospheric carbon dioxide](#) if human activity, such as [pollution](#), were to cause a mass die-off of plants. (SEP: 2.3; DCI: PS2.B.3)

- Atmospheric carbon dioxide will go down because there is more photosynthesis.
- Atmospheric carbon dioxide will go down because there is less photosynthesis.
- Atmospheric carbon dioxide will go up because there is more photosynthesis.
- **Atmospheric carbon dioxide will go up because there is less photosynthesis.**
- There is no change in atmospheric carbon dioxide.

Correct response:

- **Atmospheric carbon dioxide will go up because there is less photosynthesis.**

**Rationale for correct response:** Plants remove carbon dioxide from the atmosphere and store it in carbon-based molecules in a carbon sink. If there are fewer plants, carbon dioxide will continue to be put into the atmosphere by cellular respiration and fires but will not be removed by plants, so it will accumulate in the atmosphere.

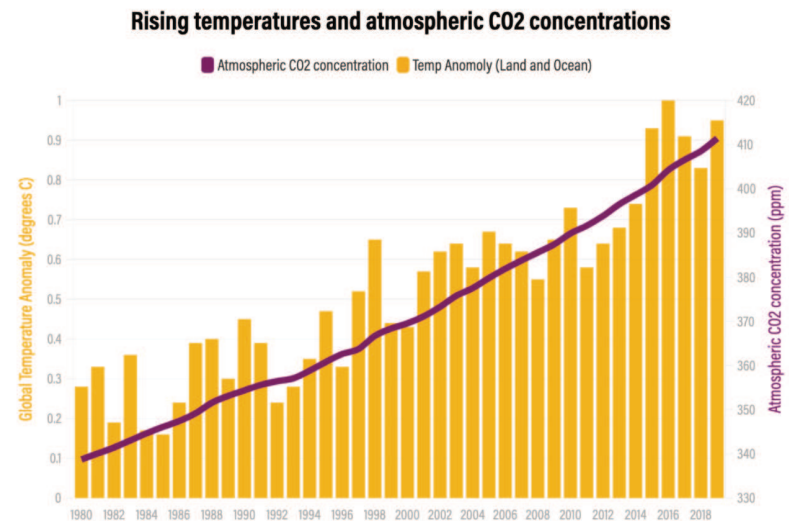
**What to do:**

- Ask students to trace the paths of carbon flow and energy transfer on the model as they reason through the question.
- Revisit the Gotta-Have-It Checklist.

## Question 2

Explain how an **increase in human-caused fires in carbon sinks leads to an increase in temperatures in the global atmosphere.** (DCI: PS2.B.3; CCC: 5.4)

- Fires are hot, and they heat the atmosphere.
- **Fires rearrange atoms in the system into carbon dioxide. This carbon dioxide and energy transferred from the system go into the atmosphere. Increased carbon dioxide in the atmosphere traps energy in Earth's system.**
- Fires rearrange atoms in the system into carbon dioxide. This carbon dioxide is hotter than the carbon dioxide already in the atmosphere, so it increases the atmosphere's temperature.
- Fires directly transfer energy into the atmosphere due to their high temperature. This energy is trapped by carbon dioxide.



Source: NOAA National Centers for Environmental Information (NCEI) and Global Monitoring Laboratory (GML)

Note: anomaly in land and ocean surface temperature relative to the 20th century average

NOAA National Centers for Environmental Information (NCEI) and Global Monitoring Laboratory (GML)

WORLD RESOURCES INSTITUTE



**Correct response:**

- Fires rearrange atoms in the system into carbon dioxide. This carbon dioxide and energy transferred from the system go into the atmosphere. Increased carbon dioxide in the atmosphere traps energy in Earth's system.

**Rationale:** Fires burn carbon sinks, which release carbon dioxide from carbon-based molecules in plants. These carbon dioxide molecules are not significantly different from those in the atmosphere. Increasing the concentration of carbon dioxide traps more energy from the Sun. There is not enough energy from burning carbon sinks to heat the entire atmosphere.

**What to do:** Ask students to look at the model in question 1 in addition to the graph above to trace through the system. Ask students to describe the greenhouse effect. Ask students if there would logically be sufficient carbon dioxide or energy from fires to warm the entire atmosphere.

### Question 3

How has the day's lesson helped you make progress toward a question that you contributed to the Driving Question Board (or to a related phenomenon)?

**What to look for in response:**

*Accept all responses.* Validating these responses engages students in activating their **relevance** and **interest** in these issues, which can motivate future questions.

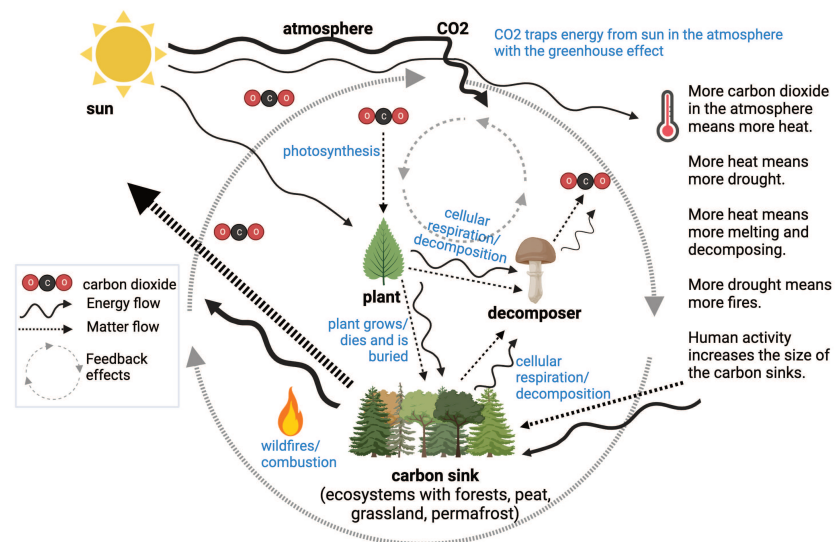
**What to do:**

Encourage students to read through their Progress Trackers to find answers to some of the DQB questions..

#### Question 4

Use the model above to predict which of the following would interrupt the feedback effect from wildfires that causes increasing carbon dioxide (matter) and rising temperatures (energy) in the atmosphere. (SEP: 2.3; CCC: 5.4)

- Introducing herbivores to an ecosystem with a large carbon sink.
- Planting more trees.
- Harvesting a small percentage of the plants in a carbon sink that could burn.
- All of the above.
- None of the above.



Illustrations created by OpenSciEd in BioRender

Correct response:

- All of the above.

Rationale: Herbivores are not in the model. Adding them would redirect carbon and energy out of the carbon sink so less plant matter is available to burn. Planting more trees and adding them to the model increases the rate of photosynthesis and could draw more carbon dioxide out of the atmosphere. Harvesting plants in a carbon sink reduces the size of the carbon sink available to burn.

What to do: If students only choose one of the items above instead of all 3, consider assigning them to a case study in Lesson 10 that addresses an idea they missed. Some students may be able to rationalize their choices if given a chance to explain their answers orally using the full complexity of the model.

#### Question 5

We developed a quantitative model based on the Gotta-Have-It Checklist and the results of the simulation. How did modeling this help you understand why carbon dioxide and temperature levels in the atmosphere are rising together? (SEP: 2.3)

**What to look for in response:** *Note: These could be different for each student.*

- Students may mention how the simulations allowed them to quantify the ways carbon dioxide might accumulate in the atmosphere.
- Students may mention that developing the class consensus model helped them understand feedback effects that cause increasing levels of carbon dioxide and rising temperatures.

**What to do:**

Encourage students to think about activities they did during the lesson that caused “aha moments” to help them explain the relationship between carbon dioxide and temperature.

#### Question 6

How did focusing on energy and matter help you understand: (CCC: 5.4)

- How carbon cycles through the subsystems in our model? and/or
- The environmental impacts of carbon cycling?

**What to look for in response:** *Note: These could be different for each student.*

- Students may mention how recording energy and matter for each step of the simulation helped focus on the relationship between them.
- Students may mention how drawing arrows explaining how both energy and matter cycle through the system helped build understanding of how temperatures rise.

**What to do:**

If students have difficulty answering, ask them to look at artifacts they produced during class like the class consensus model, Gotta-Have it Checklist, and simulation results.

#### Question 7

How did you help someone or how were you helped by someone in class today?

**What to look for in response:**

- Students articulate a possible struggle in the lesson, like revising the Gotta-Have it Checklist, developing the class consensus model, or filling out the Progress Tracker. They explain what someone said or did or what they said or did to help with one of the following:
  - Revise or add ideas to the checklist.
  - Develop and clarify ideas.
  - Contribute to the class discussions.
  - Build an encouraging community.

**What to do:** Depending on student responses, it may be beneficial to revisit the Community Agreements.

- If many students do not name another student, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science and engineering ideas.
- If many students do not explain what the other student did to help them, revisiting the Community Agreements may encourage students to think about what specific agreement the classmate was adhering to that caused them to be helpful.

# Responses to Case Studies

**Please note:** This document shows sample student responses. Note that this is not an exhaustive list of responses to these questions. Students may not generate all of these ideas on their own, or they may generate additional ideas beyond the ones listed here. The key ideas shown here are suggestions for important ideas the students may have. It is important to use the words and ideas that your students bring up and agree upon during discussion and in their writing. Actively look for different ways students share and represent their ideas as an opportunity to communicate to your students that different ways of representing our thinking are valuable, such as in words, pictures, speech, and movement.

## Prescribed Burn Case Study:

We figured out that prairie/grassland/savanna managers set prescribed burns for a few reasons: to remove dead vegetation so sunlight hits new growth. Indigenous peoples have been using prescribed burning for thousands of years. We look at the history of prescribed burning in Wisconsin and the resources available to the community on the practice from the Wisconsin Department of Natural Resources.

## Grazing Case Study:

We figure out that the reintroduction of grazers is essential for restoring prairie/grassland/savanna ecosystems. Grazer populations declined due to humans historically exterminating these populations, and we have figured out that a decrease in grazers leads to an increase in wildfires. This is because grazers help control plant growth, naturally creating firebreaks in grassland ecosystems and reducing the amount of available carbon. An example of this is how cattle grazing on a half-mile wide targeted strip of cheatgrass near Beowawe, Nevada created a firebreak that helped limit a rangeland fire.

## Cultural Burn Case Study:

We read/watched a video about collaborations between Aboriginal people (Dja Dja Wurrung) and government organizations in Victoria to return cultural burns to the landscape. The Dja Dja Wurrung (and other Indigenous peoples in other parts of the world) used burns for generations to successfully manage forests and other diverse habitats. Colonization changed priorities, stopped fires, and caused forests to change. Many tribes are trying to bring back Indigenous practices, and non-tribal managers are learning and using these techniques as well.

## Tree Planting Case Study:

The USDA Forest Service in 2021 launched a goal to restore deforested areas of the National Park System. We remember that plants form the base of the food web, with the rest of the ecosystem depending on plant life for survival. Reforesting allows us to accelerate the renewal of forest benefits, like carbon sequestration, that were lost with deforestation. The USDA Forest Service has opportunities to increase reforestation rates on 1.3 million acres of national forests, including 700,000 acres of tree planting and 600,000 acres of activities to ensure successful natural regeneration. Planting trees can remove carbon dioxide from the atmosphere and reduce atmospheric temperatures.

### 1. What are the four management techniques described in the case studies?

- A. Prescribed burn to reduce the amount of grass that can burn
- B. Cattle graze to control the amount of grass that can burn
- C. Cultural burning to reduce forest fires, a collaboration between Indigenous groups and government groups
- D. Plant trees after a fire to restore habitat and take in carbon dioxide.

### 2. How are they similar?

Prescribed burning and cultural burning are small burns of the carbon sink to prevent larger burns.

Cattle grazing is like prescribed burns and cultural burns because they reduce the size of the carbon sink to prevent larger burns.

### 3. How are they different?

Tree planting happens after a bad wildfire comes through and restores an ecosystem, and the other three prevent wildfires from occurring by reducing the size of the carbon sink.

# UDL for Jigsaw Readings

UDL Guidelines have been incorporated into the Lesson 10 jigsaw reading of case studies, including:

| Engagement                                                                                                                                             | Representation                                                                                                                                                                                                                                                         | Action & Expression                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Purposeful & Motivated                                                                                                                                 | Resourceful & Knowledgeable                                                                                                                                                                                                                                            | Strategic & Goal-Directed                                                                                                                                                                                                                                                                   |
| <b>Recruit interest:</b> Allow students to choose readings. <b>Sustaining effort:</b> Jigsaws are social, and all participants are treated as experts. | <b>Perception:</b> Electronic format supports screen reading; images support background knowledge. <b>Language &amp; Symbols:</b> We pay attention to structure and text features. <b>Comprehension:</b> Students access key information relevant to the big question. | <b>Physical action:</b> Using computers optimizes access to translation/screen readers. <b>Expression &amp; Communication:</b> The lesson encourages use of text features. <b>Executive Function:</b> Students have a distinct goal/purpose for reading and use handouts to organize ideas. |

Additionally, the case studies for Lesson 10 contain specific text structures and design features that benefit **all readers** and can be applied to other texts your students may encounter:

1. **Images & graphics:** There is a reason “a picture is worth a thousand words.” Images help readers engage with the text on a sensory level before the reading activity begins. An image that is closely related to the text’s main content can activate sensemaking that includes students’ previous experiences, cultural funds of knowledge, and curiosity.
2. **Titles, subtitles, and other section names:** Titles highlight the purpose of the text and “set the stage” for students to make conceptual connections to the text. Students can use their background knowledge and cultural funds of knowledge to connect with the reading right away.
3. **Language register:** Science articles can take on different registers of language depending on the audience and purpose. Articles written for youth may have more colloquial language, while articles written for professionals will have more highly specialized language. While specificity is important, it should not come at the expense of general comprehension for any audience. One general guideline is the 90% rule: If 1 in 10 words is unfamiliar to students, the reading or text is not easily comprehensible.

The Google versions of these articles are accessible to screen-reading technology and online translator services.

Note that while the scientific information in each of these case studies is equally rigorous, they are written at different reading levels to support differentiation. You may choose to group students strategically so that students who need more support with obtaining information from scientific texts are distributed among mixed-expertise groups or are assigned case studies with a less complex reading level within their group, while students who are looking for a challenge are in groups assigned case studies at a more complex reading level.

| Reading | Universal Design Features | Differentiation Guidance |
|---------|---------------------------|--------------------------|
|---------|---------------------------|--------------------------|

|                                   |                                                                                                             |                                                                                                                                                                                                                                                                                                                                                          |
|-----------------------------------|-------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Prescribed Burn Case Study</i> | <ul style="list-style-type: none"><li>• Section titles</li><li>• Images</li><li>• Companion video</li></ul> | This reading is comparatively long and therefore a good fit for stronger readers. Alternatively, since the reading is broken down into sections with headings and the concepts are accessible, another option would be to divide this reading among several readers. The drone video of a prescribed burn allows students to deepen their understanding. |
| <i>Grazing Case Study</i>         | <ul style="list-style-type: none"><li>• Section titles</li><li>• Images</li></ul>                           | This readings relatively short length and sentences help make it more accessible. While targeted grazing is likely a new topic to many students, the images in the reading will help students create a visual understanding of the topic.                                                                                                                |
| <i>Cultural Burn Case Study</i>   | <ul style="list-style-type: none"><li>• Short overall length</li><li>• Companion video</li></ul>            | This reading is the shortest but still has challenging vocabulary and concepts. It would be a good choice for students who like to discuss ideas and create meaning together. The companion video allows students another pathway to access the content.                                                                                                 |
| <i>Tree Planting Case Study</i>   | <ul style="list-style-type: none"><li>• Section titles</li><li>• Images</li></ul>                           | This article is about forest management before and after wildfires and focuses on the importance of planting trees. Most students are likely familiar with the concepts presented and can access background knowledge to help with comprehension.                                                                                                        |

References

CAST (2018) Universal Design for Learning Guidelines version 2.2. Retrieved December 14, 2022, from <https://udlguidelines.cast.org/>

# Smokey Bear Optional

**Acknowledge the historical context for fire management solutions.** Say, *Before we talk about our ideas for solutions, let's see what solutions may have been used in the past.* Ask students if they know or have heard of any fire management solutions in places around where they live, have visited, or have heard of in the media. Ask them to share those with the class. Students may bring up Smokey Bear. If not, say, *I want to introduce you to a solution designed in the US that I know about.* Explain to students how America used the Smokey Bear campaign as a part of their fire management policy and that it is the longest running public education campaign in the US.

**Key for Engineering Design Organizer**

|                                                     | Criteria                                                   | Constraints                                                                                                              |
|-----------------------------------------------------|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| Lesson 10 Case Studies<br><i>Grazing Case Study</i> | Reduce the amount of fuel available for a fire.            | People might not want to set controlled burns so close to neighborhoods.<br><br>There are no cattle grazing in the area. |
| Home Learning                                       | Many of the homes in my community would be safe from fire. | The terrain is difficult to get around to fight a fire if one were to break out.                                         |
| Smokey Bear Campaign                                | The number of human-caused wildfires decreased.            | Trying to get people to care enough to change their behavior in the forest.                                              |





## Lesson 11: Answer Key

# Fire Solutions Sample

**Please note:** This document shows sample student responses to some of the questions on *Prioritizing Criteria/Constraints*. Note that this is not an exhaustive list of responses to these questions. Students may not generate all of these ideas on their own, or they may generate additional ideas beyond the ones listed here. The key ideas shown here are suggestions for important ideas the students could include. However, it is important to adopt the words and ideas your students use and agree upon during discussion and in their writing. Your class's ideas could be articulated differently and may include other ideas not listed here. Actively look for different ways students share and represent their ideas as an opportunity to communicate to your students that different ways of representing our thinking are valuable, such as in words, pictures, speech, and movement.

### Part 1: *Prioritizing Criteria/Constraints*

Revisit *Fire Risk Home-Learning* to go to <https://wildfirerisk.org/explore/> to look at data about your community's fire risk. An additional source of data is the Vulnerable Populations tab to give you information about groups of people in the area that may need specific considerations in your fire management solution.

1. What community (city name, neighborhood name, zip code, etc.) have you selected?

Answers will vary.

2. Components of the community to identify:

- At least one important plant and animal species that live in the area
- Other living parts of the system that could be important to the health of the ecosystem
- What are the sources of water (rivers, streams, ocean, water table, etc.) that would need to be protected in a fire management plan?
- Are there other lands and places (canyon, nature reserves, community gardens, etc.) in the area that are important to the humans and nonhumans of the community?
- Who are the different groups of people that live in this area? Who is most vulnerable (people over 65, people with limited English, people with disabilities, etc.)?

Answers will vary based on question 1. Answers could include:

- Various key plants and animals
- Important parks, protected areas
- Specific rivers, lakes, wetlands
- Homes, important buildings, monuments
- Individuals or groups of people that may require special protection or considerations

3. Who holds the power to make decisions for the community (mayor, city manager, fire chief, Board of Trustees, etc.)?

Answers will vary based on question 1. Some possibilities include:

- Government
- People currently living on the land/colonizers

4. Use the table below to list the criteria and constraints of your community fire solution.

| Criteria (guidelines used to judge a solution)                                         | Constraints (limits on a solution)                                                                                                                                                |
|----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Protected biodiversity.                                                                | We need to make sure it is affordable so that people are able to implement it.                                                                                                    |
| Keep carbon in carbon sinks.                                                           | Lots of people want the land for different purposes.                                                                                                                              |
| Protect vulnerable places in our community from burning.                               | It will be ugly if there is no landscaping.<br>Native plants are not always pretty.<br>It is expensive to have firefighting equipment.                                            |
| Maintain places for people to live/get food, etc.                                      | People like living in places that are prone to burning. They do not want to move.<br>People do things that start fires.<br>More people keep coming here and need a place to live. |
| Reduce the amount of matter and energy (fuel) available for fire.                      | It is expensive to hire people to do the work of reducing the amount of matter and energy.<br>We do not own the property that might burn.                                         |
| The solution includes multiple perspectives and ideas from different interest holders. | The decision-makers cannot agree on what to do. They have different priorities.<br>We have limited time to find a solution. Takes more time to include multiple interest holders. |

## Part 2: Prioritizing Criteria from *Prioritizing Criteria/Constraints*

- Pick two criteria from above. Write them in the two left boxes in the table below. Then work with your team to break them down into smaller/simpler pieces that could be more easily managed in your fire solution. *\*Please note that these criteria may be broken down even further, and many students might do so. Criteria will vary greatly depending on the system for which the solution is being designed. Additionally, the sample answers below are system-generic, such as "we need plants," but please encourage students to name specific plants and animals for their system.*

| Criteria              | Simpler Criteria                                                                 |
|-----------------------|----------------------------------------------------------------------------------|
| Protect biodiversity. | There is an increase in living plants that take carbon in and store it.          |
|                       | Protected redwood trees.                                                         |
|                       | Different species of animals that eat plants are plentiful.                      |
|                       | The endangered butterfly that lives here is protected and increasing in numbers. |

|                                                                   |                                                                                                     |
|-------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| Reduce the amount of matter and energy (fuel) available for fire. | Large numbers of a wide variety of decomposers that eat plants and animals can be seen in the soil. |
|                                                                   | Resilience can be observed in the ecosystem after disturbances over time.                           |
|                                                                   | Forests do not contain large amounts of underbrush.                                                 |
|                                                                   | If fires break out, they are smaller and less severe.                                               |
|                                                                   | Landscaping around homes is not likely to burn.                                                     |
|                                                                   | Landscapes are wet and less likely to burn.                                                         |

### Part 3: *Designing Fire Solutions*

1. Create solutions that align with your simpler criteria. (Note some simpler criteria may have multiple solutions.)

| Criteria              | Simpler Criteria                                                                                    | Solutions                                                                                                                                                                                                                     |
|-----------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Protect biodiversity. | There is an increase in living plants that take carbon in and store it.                             | Remove invasives and plant native plants.                                                                                                                                                                                     |
|                       | Protected redwood trees.                                                                            | Look into camping and campfire rules near redwoods to potentially add more restrictions.                                                                                                                                      |
|                       | Different species of animals that eat plants are plentiful.                                         | Bring in different species of native animals that eat the native plants.                                                                                                                                                      |
|                       | The endangered butterfly that lives here is protected and increasing in numbers.                    | Make sure that the plants that the native butterfly needs are available, and add signage so that the community knows that it is a protected area.<br><br>Conduct regular surveys to monitor endangered butterfly populations. |
|                       | Large numbers of a wide variety of decomposers that eat plants and animals can be seen in the soil. | Perform regular soil analyses to monitor soil health so decomposers can thrive.                                                                                                                                               |
|                       | Resilience can be observed in the ecosystem after disturbances over time.                           | Plant native species and bring in native animals to increase resilience.                                                                                                                                                      |

|                                                                   |                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------------------------------|-------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Reduce the amount of matter and energy (fuel) available for fire. | Forests do not contain large amounts of underbrush.   | Do cultural or prescribed burns once per year. Have Indigenous groups and fire management groups develop regular strategies for the best time of year and how to do these burns to ensure a healthy ecosystem.                                                                                                                                                                                                                                                                                                                                 |
|                                                                   | If fires break out, they are smaller and less severe. | Let small wildfires burn. Have community groups work with fire management groups to use drones and other technology to report and perform surveillance to allow smaller wildfires to reduce fuel loads.<br><br>Work with community groups, Indigenous populations, and fire management groups to map the most effective places for fire breaks, create the fire breaks, and maintain the fire breaks.                                                                                                                                          |
|                                                                   | Landscaping around homes is not likely to burn.       | Cut and remove trees near homes so there is less to burn, creating fire breaks. Offer incentives for homeowners to remove brush near homes and have fire management do so in areas that are outside homeownership.<br><br>Create a communication system that includes more languages so more people participate. Our largest vulnerable population speaks limited English, so we need to communicate our fire management plan, emergency plans, and reporting plans in Spanish and Mandarin to be more inclusive and reduce language barriers. |
|                                                                   | Landscapes are wet and less likely to burn.           | Create a pond where dead plants get trapped and become peat. Look for areas of slow draining for a pond to help start a carbon sink.                                                                                                                                                                                                                                                                                                                                                                                                           |

1. What are the intended effects of the change to the system of carbon and energy in our community?

Answers will vary. Look for students to say the largest intended effect is to reduce carbon going into the atmosphere, to manipulate the size of carbon sinks, or to reduce the size and/or intensity of fire.

2. How will these intended effects benefit nonhuman and human components of the system?

If less carbon goes into the atmosphere, then the temperature will hopefully not increase as much (leading to less fire and other problems). More biodiversity means more food for animals. There will be better air quality and less water pollution.

3. What barriers are there to implementing the change? How might you address those barriers?

Answers will include some of the following:

Barriers:

- We need to figure out which species to plant or add to make sure that it does not affect the system in ways we do not know about yet.
- There is a possibility of technical difficulties in reaching remote places to create fire breaks and remove plants.
- We need to figure out how to protect homes near prescribed burn sites.
- Not everyone will listen to our solution.
- People may not know how to do prescribed or cultural burns.
- People might have different rights to the places, lands, and waters where we are trying to manage fire.
- Private landowners may not want to participate.
- People may not be able to afford the changes we suggest.
- The government may not have the funds to pay for new fire breaks.

Ways to address the barriers:

- Research what happened when other communities investigated new species.
- Use helicopters and drones to reach remote places.
- Incentivize participating in the solution.
- Negotiate with different landowners. Set up collaborations where everyone wins.
- We will need to raise taxes to pay for this.
- Maybe we can pay people to participate.
- We can provide free labor to clear brush from homes.
- We can create community partnerships between different organizations that have the same goals to strengthen our reach.
- Indigenous groups could teach the government agency how they do cultural burns like they did in Victoria so more people know how to do the work properly.

## Lesson 11: Answer Key 1

# Progress Tracker Key

Please note that while this Progress Tracker key is written in text, you should look for student ideas in writing, images, models, and other formats chosen by your students that they think best explains their thinking. Additionally, these ideas will vary based on your students' ideas about the phenomenon in each lesson. This key is just a guide to help show some possible student ideas seen in the field test of this unit.

### Unit Driving Question(s)

Lesson 1: *What causes zombie fires to burn under the ice, and what are the consequences?*

Updated in Lesson 6: *What causes fires in other ecosystems/sinks to burn?*

Updated in Lesson 10: *How do we design solutions to manage the impacts of fires?*

\*Note these questions are generated by the class and will vary based on your classroom.

|                                                                           | What we figured out (WWFO)                                                                                                                                                                                                                                                                                                      | How does WWFO help us make progress on our Driving Question about zombie fires?                                       | How does WWFO connect to me or my community or have a larger-scale impact?            | What questions do I have now?                                                                                                                                                                      |
|---------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Lesson 1:</b> How can fires burn under ice and release so much carbon? | <ul style="list-style-type: none"> <li>-Zombie fires burn under ice throughout the winter.</li> <li>-In zombie fires, peat is burning in the thawing permafrost.</li> <li>-Lots of carbon is put into the air when these zombie fires burn.</li> <li>-Zombie fires are not very common but are becoming more common.</li> </ul> | We need to know more about what is happening with the matter and energy that allows zombie fires to burn underground! | If these new zombie fires are burning, are there other new fires happening elsewhere? | <ul style="list-style-type: none"> <li>- What is peat?</li> <li>- Why is peat burning?</li> <li>- What is permafrost?</li> <li>- What is needed for fires to burn/how does fire happen?</li> </ul> |



|                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                           |
|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Lesson 2:</b><br/>What is peat and why does it burn so much?</p>      | <ul style="list-style-type: none"> <li>- Peat forms when plants die year after year, fall to the bottom of a wetland, and get buried over thousands of years. For some reason, the plants do not break down, and they store lots of carbon and energy.</li> <li>- Permafrost is frozen plants and animals, and ice and peat can be frozen inside it. When permafrost melts, it releases carbon-containing gasses. Peat can be frozen inside permafrost and burned when it thaws.</li> </ul> | <p>Peat contains carbon that is released into the atmosphere as carbon dioxide when it burns. The peat must be storing lots of energy somehow because it can burn and release heat and light.</p> | <p>I'm worried that peat and permafrost store huge amounts of carbon that are starting to be released by the fires and warming temperatures. Won't that affect climate change and pollute the air in my community? People around the world are responsible for the rising temperatures that are causing these fires. We should think about the consequences of our actions.</p> | <p>-Why didn't the vegetation that formed peat decompose?<br/>-How did peat and permafrost come to store so much carbon?</p>                                              |
| <p><b>Lesson 3:</b><br/>Why is there so much energy and matter in peat?</p> | <ul style="list-style-type: none"> <li>-There is so much peat because the dead plants in peat are decomposing at a very slow rate due to the cold temperature in the permafrost.</li> <li>-The carbon in the peat would normally be used (along with oxygen) by decomposers for energy and converted to carbon dioxide and water through cellular respiration.</li> <li>- The matter and the energy in the peat are staying there in what is called a carbon sink.</li> </ul>               | <p>Because the peat decomposes at such a slow rate, if the permafrost melts, all the energy and matter in the peat is available to burn, and it can burn for a very long time.</p>                | <p>It seems like we should try to keep the peat where it is and not burn it.</p> <p>Does peat form in the pond in the park?</p>                                                                                                                                                                                                                                                 | <p>How can there be so much peat in the Arctic if no plants grow there?</p> <p>How did the peat get there in the first place if there is snow and ice and it is cold?</p> |

|                                                                                                                      |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                          |                                                                                                                        |                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| <p><b>Lesson 4:</b><br/>How did so much plant energy and matter get into the peat in the zombie fire system?</p>     | <p>-Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds.</p> <p>-As solar radiation in the Arctic decreased, many plants died, and peat and permafrost were formed.</p>                            | <p>There was so much more energy from the Sun because of the Earth's tilt 10,000 years ago, which was enough to make all that peat that got trapped under the ice.</p> <p>If plants have lots of energy, they can capture energy from the Sun, and then they can store lots of energy inside of them that can become energy to burn!</p> | <p>How are the plants in different places around Earth and in my community affected by changes in solar radiation?</p> | <p>If plants get more sun, do they use more carbon?</p>                                         |
| <p><b>Lesson 5:</b><br/>How do zombie fires disrupt the flow of energy and cycle of matter in Arctic ecosystems?</p> | <p>-Through photosynthesis, plants convert carbon dioxide and water into sugar and oxygen.</p> <p>-More solar energy means more carbon dioxide is captured and stored by plants as sugar and releases oxygen.</p> <p>-Plants convert excess sugar into larger carbon-based molecules</p> | <p>We noticed the peat in zombie fires burned for a long time. Figuring out that the plants that made the peat contain so many carbon molecules and so much energy because those plants grew when there was a lot of sunlight helps explain how the fires keep going.</p>                                                                | <p>We wonder what this means for plants in our community or with changes in our area over time.</p>                    | <p>How does this effect plants in other systems?</p> <p>How will this change in the future?</p> |

|                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                         |                                                                                                                                                             |                                                                                                                                                                                                                               |
|----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Lesson 6:</b><br/>How do zombie fires disrupt the flow of energy and cycle of matter in Arctic ecosystems?</p> | <ul style="list-style-type: none"> <li>- Photosynthesis captures energy from sunlight and is converted to chemical energy in carbon-based glucose fuel, taking carbon out of the air and into the plants/peat.</li> <li>- When plants have extra energy and matter, they store the glucose they created as larger molecules.</li> <li>- Plants in the Arctic die and get submerged where it is too cold for decomposition to happen quickly.</li> <li>- The energy in the plants is stored underwater.</li> </ul> <p>Generations of plants die on top of one another, and more and more matter and energy is stored in the peat.</p> <ul style="list-style-type: none"> <li>- Peat is made of partially decomposed layers of plants.</li> <li>- Permafrost melts, and peat is exposed. Peat can now decompose and burn.</li> <li>- Zombie fires burn huge carbon sinks in the peat/permafrost system and release carbon into the air.</li> </ul> | <p>Zombie fires have lots and lots of carbon stored in the permafrost/peat system. This means they can burn for a long time and release lots of carbon dioxide into the atmosphere.</p> | <p>We are worried that there might be carbon sinks in or near our communities that could burn like the zombie fires and release lots of carbon dioxide.</p> | <p>I think I can explain the zombie fire system now. Is there anything else going on?</p> <p>How will we deal with all this carbon being released if more and more fires happen?</p> <p>How could the fires be prevented?</p> |
|----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|                                                                                                        |                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Lesson 7:</b><br/>Where and what is happening to other carbon sinks?</p>                         | <p>-Many different ecosystems have carbon sinks that result from the flow of energy and matter from the Sun.<br/>-There are common factors in ecosystems that reduce the flow of energy and matter and create carbon sinks more likely to burn.<br/>-Fire increases the flow of matter and energy from the biosphere to the atmosphere.</p> | <p>There must be a really delicate balance between where matter and energy are in a system to make sure that it does not become more likely to burn. People's historical decisions impact what is happening today.</p> | <p>We had bad fires in our community last year. I wonder if we made them worse because there were homes in the forest there.</p> <p>I want to know about the consequences for me if these places burn. Is there a lot of carbon dioxide released related to climate change?</p> <p>I'm not really sure how these fires in other parts of the world matter to me.</p> | <p>-How much carbon dioxide is released when these carbon sinks burn?<br/>-Do these fires contribute to climate change?<br/>-What can be done to stop all of this burning?<br/>-Could we bring back Indigenous burning practices?<br/>-Should the government stop the fire suppression policies?<br/>-Are there any carbon sinks near me that could burn?<br/>How can we protect them?</p> |
| <p><b>Lesson 8:</b><br/>Why should we be concerned that carbon sinks around the world are burning?</p> | <p>-Increased carbon dioxide in the air causes temperatures to rise.</p>                                                                                                                                                                                                                                                                    | <p>We see that there is a directional hypothesis that if you increase carbon dioxide, then the temperature will increase as well.</p>                                                                                  | <p>Now that we have done this investigation, it is even scarier when I watch the news and they talk about carbon dioxide levels in the air and the oceans rising.</p>                                                                                                                                                                                                | <p>-Does the increase in carbon dioxide increase the temperature on Earth like it does in the bottles?<br/><br/>-How can we protect carbon sinks from burning?<br/><br/>-Can we create more carbon sinks?<br/><br/>-People do things that make carbon sinks vulnerable to burning. What can they do to stop them?</p>                                                                      |
| <p><b>Lesson 9:</b><br/>Why should we be concerned that carbon sinks around the world are burning?</p> | <p>-Increasing global carbon dioxide levels in the atmosphere correlate with rising global temperatures.<br/>-Human actions can increase the amount of carbon available in the carbon sink to burn, leading to more carbon dioxide being released into the atmosphere.</p>                                                                  | <p>As carbon dioxide levels rise in the atmosphere because of wildfires, global temperatures rise. Energy from the Sun is transferred to the atmosphere, heating it up.</p>                                            | <p>Burning carbon sinks has a large-scale impact on the planet. We've had really hot summers here, and there have been some fires because of the drought. I'm concerned about this getting worse. It is scary that temperatures keep rising. I'm starting to understand how small-scale actions can have big-scale consequences.</p>                                 | <p>If plants take carbon dioxide out of the atmosphere, couldn't we just plant more trees to help with climate change?<br/><br/>How do plants respond to rising carbon dioxide levels?</p>                                                                                                                                                                                                 |

|                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                              |
|-----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Lesson 10:</b><br/>How can we help manage the matter and energy in fire systems?</p>                | <p>-We learned that successful fire management disrupts the positive feedback loop we saw in Lesson 9.<br/>-Prescribed and cultural burning reduces the amount of fuel available to burn, restoring grazers to ecosystems reduces the amount of fuel available to burn, and planting trees in areas that have been deforested restores the matter and energy to the food web.<br/>-Only a small fraction of matter and energy moves from producers to consumers, but it is enough to reduce big wildfires if done correctly.</p> | <p>Restoring essential aspects of ecosystems helps reduce the amount of carbon sink available to burn in wildfires.</p>                                                                | <p>I was worried going into this lesson that there was little we could do to stop wildfire, but after learning about these different techniques, I am feeling more hopeful.</p> <p>I hope that my own community does more to help educate people on Indigenous knowledge systems and how we can work together with people who have different perspectives to make fire management plans.</p> | <p>-Can we restore parts of other ecosystems using these management techniques?<br/>-What does it take to actually use these strategies in other places?</p> |
| <p><b>Lesson 11:</b><br/>What decisions can we make to help manage fire in communities we care about?</p> | <p>-Criteria need to be broken down into simpler ones to manage fire so we can see who will be impacted (human and nonhuman) by our decisions.<br/>-Making decisions involves and impacts people at many levels in the systems we care about.<br/>-The places, lands, and waters we care about are complex, and decisions about the priority of certain criteria over others (trade-offs) may be needed.</p>                                                                                                                     | <p>There are a lot of different types of matter in the communities we care about, which means we have to break criteria down into smaller pieces to balance the matter and energy.</p> | <p>It is very complex to manage the needs of the communities we care about and at the same time make decisions that are best for balancing matter and energy in those communities!</p>                                                                                                                                                                                                       | <p>We understand in this context, but is this always true?</p>                                                                                               |

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## Lesson 12: Answer Key

## Dead Zone Key

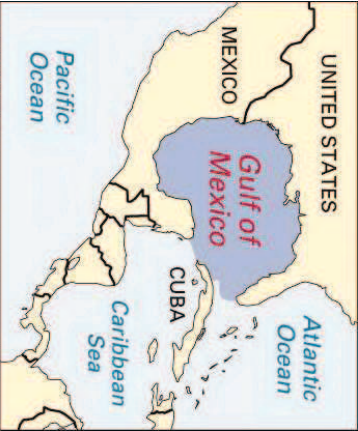
This task is aligned to NGSS PE:  
HS-LS2-5.

Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

| Question #  |                                                                                                                                                                                                                                                                                                               |   |   |   |   |   |   |   |   |   |    |    |    |
|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|
| 3D Elements |                                                                                                                                                                                                                                                                                                               | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| SEPs        | <b>2.3 Developing and Using Models.</b> Develop a model based on evidence to illustrate the relationships between systems or between components of a system.                                                                                                                                                  | X | X |   |   | X | X |   |   | X | X  | X  |    |
| DCIs        | <b>LS2.B: Cycles of Matter and Energy Transfer in Ecosystems.</b> Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. | X | X |   | X |   | X | X | X | X | X  | X  | X  |
|             | <b>PS3.D: Energy in Chemical Processes.</b> The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. (secondary)                                                                                                                       |   |   | X |   | X |   |   |   |   | X  |    |    |
| CCCs        | <b>4.3 Systems and System Models</b> Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.                                                                  | X | X | X | X | X | X | X |   | X | X  | X  | X  |

While some marine life, like turtles, whales, and dolphins, breathe oxygen from the atmosphere, others like fish and shrimp use gills to process oxygen that has dissolved in water. Low dissolved oxygen can create "dead zones" where aquatic life dies or leaves. Worldwide, dead zones are now 10 times more common than 50 years ago. In the U.S., their frequency has increased 30 times since 1960. The second-largest dead zone occurs every spring in the Gulf of Mexico.

The Gulf of Mexico is bordered by U.S. and Mexican states. The dead zone happens every year and is concentrated in the northern part of the Gulf. This region is an important part of the marine ecosystem and has cultural, recreational, and economic value to humans. In particular, the region affected by the dead zone produces a large percentage of fish and shrimp consumed in the U.S. Many fishers and shrimpers are immigrants, including refugees who came to Louisiana during the Vietnam War. Others, including members of the Houma tribe, are indigenous to the Gulf Coast.



Nickhammer, CC BY-SA 3.0

|                                                                                                                    |                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>Lee, E. (2019, June 24)</p> | <p>"I always had a passion for shrimping. I always loved the Gulf. For some reason when I do this, I feel like I belong there. [The dead zone] is not good. We can only do so much and ask for [God's] blessing. He'll take care of the rest."</p> <p>Tuan Tran, Vietnamese shrimper in Port Arthur, Texas</p> |
|  <p>Jim Bahn, CC BY 2.0</p>      | <p>"Sometimes we'll get thousands of pounds of shrimp a day, then the next day everything's gone. When the dead zone comes, it just kills everything."</p> <p>Dean Blanchard, 4th generation Creole shrimper</p>                                                                                               |

Reducing the dead zone's size is a goal of many interest holders.

In this task you will:

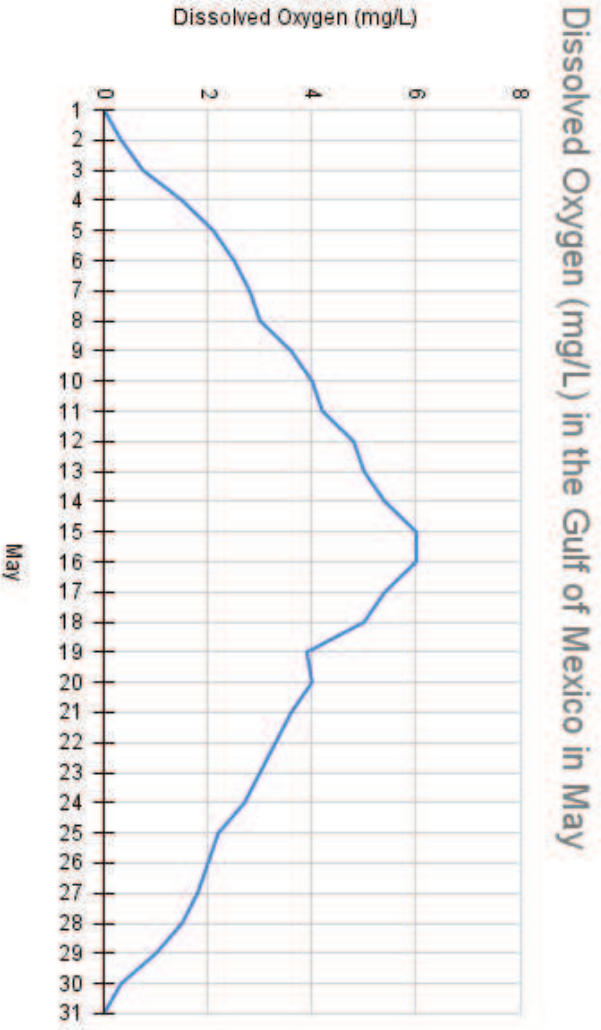
- Figure out the cause of the abrupt decline in oxygen in the Gulf of Mexico and the resulting dead zone.
- Provide an evidence-based suggestion for reducing the dead zone's size.

Part 1: What's going on with dissolved oxygen in the Gulf?

1. Prior to examining data, use your understanding of photosynthesis and cellular respiration to make an initial model. Which process do you think is causing the drop in dissolved oxygen? Explain your reasoning with words and/or drawings. (SEP 2.3; DCI: LS2.B; CCC: 4.3)

|             | Foundational Pieces                                                                                     | Linked Understanding                                                                                                                                                                                                | Organized Understanding                                                                                                                                                                                                      |
|-------------|---------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3D Elements | In this explanation, look for:<br><br>The idea that cellular respiration requires oxygen.<br><br>(1 pt) | In this explanation, look for:<br><br>The idea that cellular respiration requires oxygen and therefore moves oxygen from one system (the ocean) to another (an organism doing cellular respiration).<br><br>(2 pts) | In this explanation, look for:<br><br>Students beginning to build a conceptual model based on evidence from their investigations that cellular respiration could be causing oxygen to leave the ocean system.<br><br>(3 pts) |
| Example     | Cellular respiration uses oxygen.                                                                       | Cellular respiration uses oxygen, so this process could be taking dissolved oxygen from the ocean.                                                                                                                  | When a living thing does cellular respiration, it takes oxygen from the environment. So maybe something is doing cellular respiration and causing the drop in dissolved oxygen in the ocean.                                 |

2. To better understand the dead zone phenomenon, scientists have been monitoring dissolved oxygen levels in the Gulf of Mexico. The data in Figure 1 show dissolved oxygen in the Gulf throughout the month of May. (SEP 2.3; DCI: LS2.B; CCC: 4.3)



Data Source: Rabalais, N. N., Turner, R. E., & Wiseman, W. J. (2001).

Typically, ocean fish and shrimp require dissolved oxygen levels above 3 mg / L to survive.



Refer to the graph and note dates when:

- Dissolved oxygen is above 3 mg/L: May 8-24
- Dissolved oxygen is below 3 mg/L: May 1-8, May 25-31
- You predict there are more fish and shrimp: May 8-24
- You predict fish and shrimp start to die or leave: May 1-8, May 25-31
- You predict higher numbers of aquatic plants and organisms using photosynthesis: May 8-24
- You predict fewer numbers of aquatic plants and organisms using photosynthesis: May 1-8, May 25-31

g. You predict there is more carbon dioxide in the water: May 1-8, May 25-31

h. You predict there is less carbon dioxide in the water: May 8-24

Note: It is not important that students select the exact dates listed here, though they should be close.

## Part 2: How does oxygen dissolve into water?

There are two main ways oxygen gets dissolved in water. The first occurs when air mixes with water. More oxygen gets mixed in when the water is moving around a lot, like when waves crash, or when water flows over rocks.

The second way oxygen gets into water is when it is released by producers such as underwater plants or other aquatic life that use photosynthesis. Phytoplankton are single-celled organisms that add oxygen to water in this way, through photosynthesis.

3. What do you think typically happens to the phytoplankton population in the spring, when solar energy to the Gulf of Mexico region increases after winter? (DCI: PS3.D; CCC: 4.3)

- Increase
- Decrease
- Stay the same
- Insufficient information

3. How would this affect the concentration of dissolved oxygen and dissolved carbon dioxide in water? (DCI: LS2.B; CCC: 4.3)

- Increase oxygen concentration; decrease carbon dioxide concentration
- Decrease oxygen concentration; increase carbon dioxide concentration
- Stay the same
- Insufficient information

Although some natural factors boost Spring oxygen levels, big oxygen increases followed by a steep decrease, and a rising number of dead zones in recent decades suggest human influence.

In the late 1940s, following the end of World War II, U.S. farmers and industries began widespread use of synthetic fertilizers. The fertilizer supplies nitrogen for chlorophyll, the pigment that makes plants and phytoplanktons green, and aids energy production through photosynthesis. Water runoff from these fields carries nutrients to the Mississippi River and then to the Gulf of Mexico.

5. Which of the following could explain the big increases in dissolved oxygen observed in the first half of May? (SEP 2.3; DCI: PS3.D; CCC: 4.3)

Fertilizer runoff:

- Causes phytoplankton population to decrease because too much fertilizer can harm plants.
- Causes dead zones, where fish and shrimp suddenly die because fertilizer is toxic to them.
- Causes phytoplankton population to increase more than usual because in addition to more sunlight, the phytoplankton have more nutrients.

## Part 3: What is responsible for the drop in dissolved oxygen?

We have traced the source of increases to dissolved oxygen, but have not yet figured out where all the oxygen went to cause the dead zone.

6. Refer back to your initial model from question 1. What process did you predict was responsible for the decrease in dissolved oxygen? (SEP 2.3; DCI: LS2.B; CCC: 4.3)

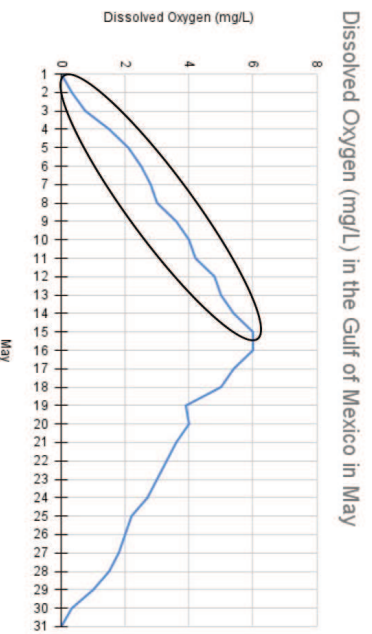
- a. Photosynthesis
- b. Cellular respiration

Answer should be consistent with the student's response to Q1. Do not score.

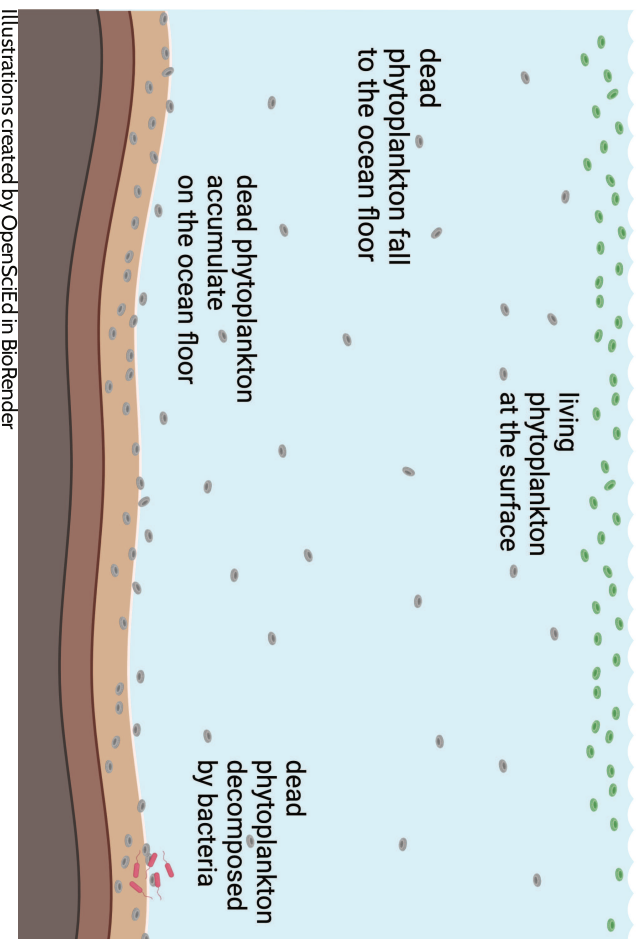
7. Each phytoplankton only lives a few days. When they die, they sink to the bottom, where they are decomposed by bacteria.

As more and more phytoplankton die and fall to the bottom, what do you expect happens to bacteria populations? (DCI: LS2.B; CCC: 4.3)

- a. Increase
- b. Decrease
- c. Stay the same
- d. Insufficient information



Data Source: Rabalais, N. N., Turner, R. E., & Wiseman, W. J. (2001).

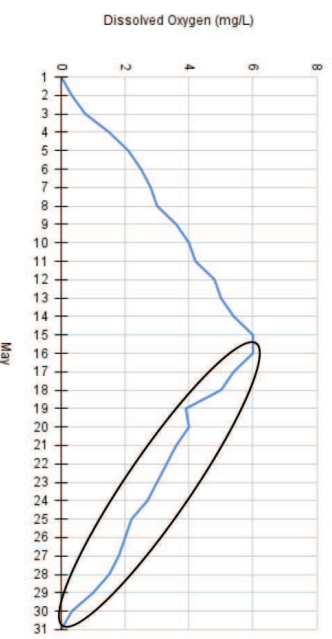


8. What process do decomposers use to rearrange matter and transfer energy? (DCI: LS2.B)

- a. Photosynthesis
- b. Cellular respiration

9. How do decomposing phytoplankton help explain what is happening to dissolved oxygen between May 15th and 31st, based on the data in Figure 2. (SEP 2.3; DCI: LS2.B; CCC: 4.3)

Dissolved Oxygen (mg/L) in the Gulf of Mexico in May



Data Source: Rabalais, N. N., Turner, R. E., & Wiseman, W. J. (2001).

| 3D Elements | Foundational Pieces                                                                                        | Linked Understanding                                                                                                                                                                                                 | Organized Understanding                                                                                                                                                                                                                                                                                                                           |
|-------------|------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|             | In this explanation, look for:<br><br>Evidence from the data that dissolved oxygen decreased after May 15. | In this explanation, look for:<br><br>The idea that cellular respiration would drive the decomposition of phytoplankton and could explain why dissolved oxygen moved out of the ocean system during this time frame. | In this explanation, look for:<br><br>Students connecting the data from the task to explain how what is happening in one component of the system (continuous decrease in dissolved oxygen) is related to what is happening in another part of the system (more and more phytoplankton being decomposed by bacteria through cellular respiration). |
| Example     | The amount of dissolved oxygen decreases between May 15-31.                                                | Bacteria use cellular respiration to decompose the phytoplankton, taking oxygen out of the ocean.                                                                                                                    | Over time, more and more phytoplankton die, and more and more bacteria grow, using up almost all the oxygen in the area.                                                                                                                                                                                                                          |

10. Put the pieces together. What is causing low dissolved oxygen and the resulting dead zone? Where does that oxygen go? (SEP 2.3; DCI: LS2.B; CCC: 4.3)

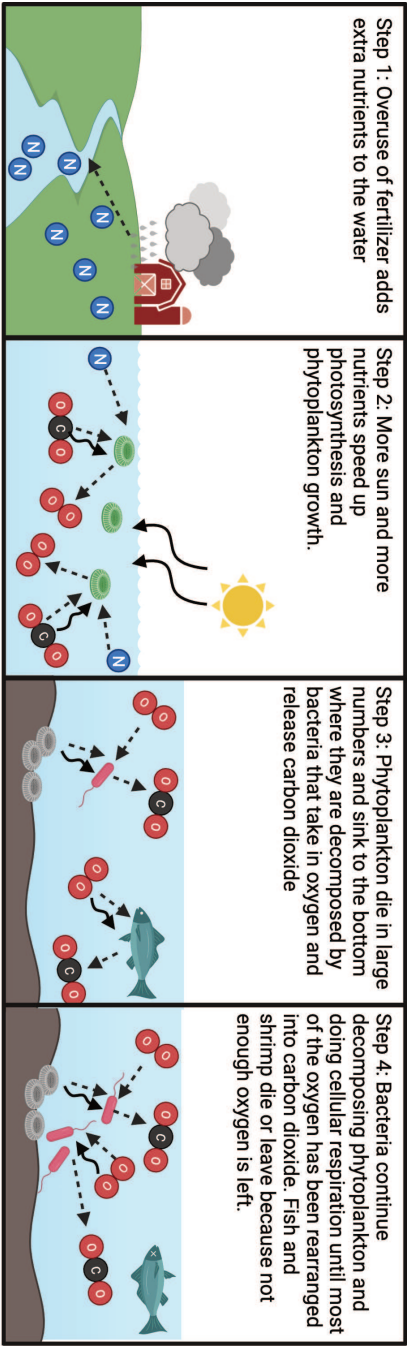
Create a revised model below using words and/or drawings. Be sure to include:

- The steps leading to low dissolved oxygen ( $O_2$ ) and dead zones.
- The roles of phytoplankton and bacteria.
- The inputs and outputs of photosynthesis and cellular respiration (include the flow of both matter and energy).
- The role of the Sun and excess nitrogen in the water.
- The effect of low oxygen on shrimp and fish and why this is the effect.
- Where the dissolved oxygen went and how it got there.

Your model can be:

- Explained visually through illustrations with labels.
- Explained in writing.
- Explained through speaking.

Choose your preference and let your teacher know. If you are writing or creating an illustration, use the space below.



Illustrations created by OpenSciEd in BioRender

| Foundational Pieces | Linked Understanding | Organized Understanding |
|---------------------|----------------------|-------------------------|
|---------------------|----------------------|-------------------------|

| 3D Elements | In this explanation, look for:                   | In this explanation, look for:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | In this explanation, look for:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|             | A link between excess fertilizer and dead zones. | <p>A model that includes 2-3 of the following relationships between parts of the system and flows of matter (oxygen) and energy through those systems.</p> <ul style="list-style-type: none"> <li>• Fertilizer runoff from farmlands results in extra nutrients in the ocean system.</li> <li>• More sunlight and nutrients speed up photosynthesis, phytoplankton take in more carbon dioxide from and release more oxygen into the ocean.</li> <li>• Phytoplankton die, and their matter is decomposed by bacteria for energy. The bacteria use oxygen and release carbon dioxide.</li> <li>• Bacteria decompose more and more phytoplankton and convert more and more oxygen from the ocean into energy and carbon dioxide. Fish and shrimp die or leave because they too, must perform cellular respiration to live.</li> </ul> | <p>A model that includes all of the following relationships between parts of the system and flows of matter (carbon and oxygen) and energy through those systems.</p> <ul style="list-style-type: none"> <li>• Fertilizer runoff from farmlands results in extra nutrients in the ocean system.</li> <li>• More sun and nutrients speed up photosynthesis and take in more carbon dioxide from and release more oxygen into the ocean.</li> <li>• Phytoplankton die, and their matter is decomposed by bacteria for energy. The bacteria use oxygen and release carbon dioxide.</li> <li>• Bacteria decompose more and more phytoplankton, and convert more and more oxygen from the ocean into energy and carbon dioxide. Fish and shrimp die or leave because they too must perform cellular respiration to live.</li> </ul> |
| Example     | Extra fertilizer causes dead zones.              | Extra fertilizer makes more phytoplanktons. When those die they are eaten by bacteria, which use up the oxygen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | See above for complete model.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

|                         |                                                                                                                                                                                       |                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Feedback/<br>What to Do | <i>Linking:</i><br>Support students to think step by step by either starting at the beginning, <i>What happens first?</i> or working backward, <i>What caused the drop in oxygen?</i> | <i>Organizing:</i><br>Ask students to explain where the oxygen goes and link the flow of oxygen to the flow of carbon in the system. | <i>Extending:</i><br>Ask students to more completely trace carbon through the dead zone phenomenon. E.g., say, <i>Where does the carbon come from that bacteria turn into CO<sub>2</sub>?</i><br><br>Share more information about the role of CO <sub>2</sub> in dead zones and ask students to add an additional step in their model. Say, <i>More CO<sub>2</sub> in the atmosphere increases temperatures, including water temperature. Less oxygen can dissolve in warm water. How does climate change affect the dead zone?</i><br><br>Push students on what type of decomposition is happening here. Would the bacteria produce carbon dioxide or methane in a low oxygen environment like the one under water? Invite them to revise the model to include tracing hydrogen atoms in sugars and methane. |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

### Part 5: Solutions

Since small streams flow into big rivers that eventually reach the oceans, both inland and coastal areas can affect the amount of dissolved oxygen in the oceans.

11. Think about where you are located. What ways does water near you make its way to the ocean? Be as specific as you can. (SEP 2.3; DCI: LS2.B; CCC: 4.3)

Do not score.

|                         |                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Feedback/<br>What to Do | If students struggle with this, consider projecting a Google map of your local area and looking for waterways, then zooming out to larger rivers. If there are no nearby streams, prompt students to consider storm drainage, gutters, and sewage. Invite students to draw analogies between their local watershed and the Gulf of Mexico / Mississippi River / dead zone systems and their components. |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 1. Sources of Nitrogen Pollution in the US

| Source of Nitrogen Pollution | Mechanism by which nitrogen enters the watershed                                                                                         | Estimated annual nitrogen contributions in US (metric tons) | Estimated annual nitrogen contributions in US (kg) |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|----------------------------------------------------|
| Agriculture*                 | Nitrogen in manure and fertilizers help crops grow. But if plants don't use it completely, it can harm air and water quality downstream. | 3.5 million                                                 | 3,500,000,000                                      |



|                     |                                                                                                                                                                                                            |             |               |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|---------------|
| Stormwater          | When rain hits urban areas, it flows over surfaces like roofs, sidewalks, and roads, taking pollutants, including nitrogen, into nearby water.                                                             | 0.3 million | 300,000,000   |
| Residential Sources | Fertilizers, pet waste, and some soaps have nitrogen that can lead to pollution if not used or thrown away correctly. More hard surfaces and certain landscaping can worsen nitrogen runoff when it rains. | 2 million   | 2,000,000,000 |
| Wastewater          | Sewer and septic systems treat waste, but they often don't remove enough nitrogen before releasing it into water.                                                                                          | 2 million   | 2,000,000,000 |

12. Consider the above data regarding the primary sources of nitrogen pollution in the US and what you know about your local area. You can also review trends in your state's nitrogen fertilizer usage found in *Nitrogen Pollution By State*. (SEP 2.3; DC: LS2.B; CCC: 4.3)

- a. Select a source of nitrogen and describe a possible action in your state or local area that would reduce nitrogen pollution in that category.

Source:

Any of the following: Agriculture, stormwater, residential sources, wastewater

Possible action:

There are many possible responses, some include:

If agriculture was selected: Reducing use of fertilizer, being careful about not overusing fertilizer, regulating fertilizer use.

If stormwater was selected: Collecting water in a rain barrel and using it to water plants to divert from storm drains, treating stormwater to remove nitrogen.

If residential sources were selected: Picking up pet waste, reducing the number of hard surfaces from a yard and replacing with plants that will take up the nitrogen.

If wastewater was selected: Removing nitrogen in the wastewater treatment facility.

- b. Add a star \* to your model in Q9 to indicate where your solution intervenes in the sequence of events that cause the dead zone.

Look for a star \* early in the sequence of events in the students model in Q9.

- c. Explain why you think this action would work to reduce nitrogen pollution and ultimately reduce ocean dead zones.

Reducing the amount of nitrogen flowing into the ocean would reduce the amount of extra phytoplankton that grow, die, sink, and then are decomposed by bacteria, which use up all of the available oxygen when doing cellular respiration.

- d. Think with numbers: Considering the pollution source you focused on, what impact on dead zones do you predict from the action you suggested compared to other possible actions?

There are many possible responses, for example:

If people in my neighborhood picked up dog poop, it would make a small dent in the amount of nitrogen runoff and on the dead zone because it is just my neighborhood. If everyone in neighborhoods that connected to the major river in my area did this, it would make a bigger impact. Since residential sources of

nitrogen all add up to be about one-third of the amount of nitrogen contributed by agriculture, and picking up pet waste is only part of that, it would have less of an impact than addressing agriculture but more than if stormwater was the focus.

|             | Foundational Pieces                                                                                                                                                                                                                       | Linked Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Organized Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3D Elements | In this explanation, look for:<br>Students selecting a source of nitrogen pollution to reduce and stating that reducing it would reduce the size of the dead zone without specifying an action or how this action would have that result. | In this explanation, look for:<br>Students selecting a source of nitrogen pollution to reduce and proposing a plausible, specific action.<br><br>Students explaining that changes to matter in one part of the system (e.g., nutrients on farmland) would affect matter in another part of the system (oxygen in oceans).<br><br>Students thinking about the relative amounts of nitrogen coming from each source and relating the action they selected to those numbers to determine scale of impact. | In this explanation, look for:<br>Students selecting a source of nitrogen pollution to reduce and proposing a plausible, specific action.<br><br>Students explaining that changes to matter in one part of the system (e.g., nutrients on farmland) would affect matter in another part of the system (oxygen in oceans).<br>When discussing changes in flows of matter and energy related to their solution, students explain mechanisms of cellular respiration leading to decreased oxygen and increased carbon dioxide in dead zones. |
| Example     | People should use less nitrogen at home. If they used less nitrogen, it would shrink the dead zone.                                                                                                                                       | People should pick up their dog poop. If people picked up dog poop, it would reduce the amount of nitrogen in local parks, which would mean less nitrogen washed into storm drains and the ocean. If less nitrogen got to the ocean, there would be better oxygen concentration there.                                                                                                                                                                                                                 | See above<br><br>Students thinking about the relative amounts of nitrogen coming from each source and relating the action they selected to those numbers to determine scale of impact.                                                                                                                                                                                                                                                                                                                                                    |



| Feedback /What to Do | Linking:                                                                                                                                                                                                                                                                                                                         | Organizing:                                                                                                      | Extending:                                                                                                                                                                                                                                                         |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                      | <p>Provide students with a list of specific actions related to the different sources of nitrogen pollution and ask them to choose one that interests them.</p> <p>Provide an exemplar model of the dead zone phenomenon as a resource and ask them to point to or say parts of the model that would change with this action.</p> | <p>Ask students to say <i>more</i> about how nitrogen concentration ultimately affects oxygen concentration.</p> | <p>Invite students to research existing organizations, community members, or government agencies working to address nitrogen pollution in their area.</p> <p>Invite students to consider what it would take to actually implement the solution they suggested.</p> |

| Foundational Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Linked Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Organized Understanding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Suggestions for instruction</b></p> <p>If the majority of the class demonstrates a foundational understanding, first take time to make sense of the scenario. Optionally, consider showing the video found on <a href="https://www.nsf.gov/news/special_reports/dead_zones/climatechange.jsp">https://www.nsf.gov/news/special_reports/dead_zones/climatechange.jsp</a> to support students in visualizing the scenario ("pre- and post-anoxia"). This video is taken underwater and shows the formation of a dead zone.</p> <p>Then lead students through a Consensus Building Discussion to come to an agreement about how the flow of matter and energy between farmlands and the Gulf result in the dead zone.</p> <p>Use prompts like:</p> <ul style="list-style-type: none"> <li>-Could someone restate our question? What are we building consensus about?</li> <li>-What are some things we can say at this point about the Dead Zone phenomenon that are supported by evidence?</li> <li>-What ideas are we in agreement about?</li> <li>-Would anyone have put this point a different way?</li> <li>-Who feels like their idea is not quite represented here?</li> <li>- We have not yet addressed _____. What might we add or change to explain this part of the dead zone system?</li> </ul> | <p>If the majority of the class demonstrates a linked understanding, push students to flesh out more components of the model, particularly linking the flow of energy and oxygen to the flow of carbon in the system.</p> <p>Consider having students share their models with a partner, then use the following model revision prompts to suggest improvements to each others' models. Then allow time for students to respond to feedback and make changes to their models.</p> <ul style="list-style-type: none"> <li>-What should be added to the model that is currently missing?</li> <li>-What should be changed about the model to make it more consistent with what we figured out about how matter and energy flow through systems?</li> <li>-What are you wondering about that is unclear in the current model?</li> </ul> | <p>If the majority of the class demonstrates an organized understanding, challenge students by asking them to link the dead zone phenomenon to the zombie fire phenomenon. Share information about the role of CO<sub>2</sub> in dead zones and ask students to add an additional step in their model. Say, <i>More CO<sub>2</sub> in the atmosphere increases temperatures, including water temperature. Less oxygen can dissolve in warm water. How do zombie fires affect the dead zone phenomenon?</i></p> <p>Then invite students to extend their thinking about possible solutions. Say, <i>If nitrogen pollution isn't the only contributor to the dead zone phenomenon, and climate change also has a role, what other actions might reduce the size of the dead zone?</i></p> |

## References

*Dead zones - special report - SOS: Is climate change suffocating our seas?: NSF - national science foundation.* NSF. (n.d.). [https://www.nsf.gov/news/special\\_reports/deadzones/climatechange.jsp](https://www.nsf.gov/news/special_reports/deadzones/climatechange.jsp)

Environmental Protection Agency. (n.d.). *Dissolved Oxygen*. EPA. <https://www.epa.gov/caddis-vol2/dissolved-oxygen>

Harnik P. G., TorStebson, M. L., & WILLIAMS, M. A. (2017). Assessing the effects of anthropogenic eutrophication on marine bivalve life history in the northern Gulf of Mexico. *Palaios*, 32(11), 678–688. DOI: 10.2110/palo.2017.033

Lee, E. (2019, June 24). "Dead zone" threatens livelihood of Mexico fishermen. VOA. [https://www.voanews.com/amp/usa\\_dead-zone-threatens-livelihood-gulf-Mexico-fishermen/6170500.html](https://www.voanews.com/amp/usa_dead-zone-threatens-livelihood-gulf-Mexico-fishermen/6170500.html)

Rabalais, N. N., Turner, R. E., & Wiseman, W. J. (2001). Hypoxia in the Gulf of Mexico. *Journal of Environmental Quality*, 30(2), 320–329. <https://doi.org/10.2134/ieq2001.302320x>

US Department of Commerce, N. O. and A. A. (2016, March 24). *Happening now: Dead zone in the gulf 2021*. Ocean Today. <https://oceantoday.noaa.gov/deadzonegulf-2021/welcome.html>

Writer, E. N. S., Negin, E., Writer, S., Writer, E. N. S., Director, K. P. S. D., Stillerman, K. P., Director, D., Scientist, A. R. I., Reznickova, A., & Scientist, I. (2021, June 7). *Ask an expert: Reviving the Gulf of Mexico's dead zone*. The Equation. <https://blog.ucsusa.org/elliott-negin/reviving-the-gulf-of-Mexicos-dead-zone/>