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LESSON

Tracking Carbon to Understand its Flow

Students learn about the Darvaza Crater and ponder what keeps it burning. Then they analyze the Keeling Curve and consider the source of the increasing atmospheric carbon dioxide. In the activities to follow, they explore fossil fuel formation, use, benefits, and consequences through a series of readings. By sorting everyday objects and diagramming a simple model of the global carbon cycle, students consider how carbon generally cycles through Earth's systems, including as fossil fuels. This lesson is part of the *Carbon Trackers* unit.

GRADES
6 - 8

SUBJECTS
Earth Science

CONTENTS
3 Activities

In collaboration with

educurious
learning that connects

ACTIVITY 1: PUTTING THE "FOSSIL" IN FOSSIL FUELS | 1 HR 15 MINS

DIRECTIONS

This activity is a part of the Carbon Trackers unit.

1. Introduce a real-life puzzling phenomenon related to fossil fuel.

- Show the video and photos of the Darvaza gas crater in Turkmenistan from the *Entering the 'Door to Hell'* article. Ask students to consider the following questions as they watch, and to be prepared to share their thoughts:
    - *How long to do you think the crater has been burning?*
    - *What do you think is causing the crater to continue burning?*
    - *Where do you think the energy in the fire comes from?*
    - (Natural gas is coming out of the Darvaza gas crater. Scientists lit it on fire in 1971, hoping to burn off all the natural gas, but it hasn't stopped burning since, indicating a larger reservoir of natural gas than originally assumed. Natural gas is a fossil fuel.)
- Pause to elicit students' ideas in response to these questions.
    - In their initial responses, students may mention the idea of "gas" burning in the crater. If so, verify their answer and introduce the term "fossil fuel" and its definition: coal, oil, or natural gas. Fossil fuels formed from the remains of ancient plants and animals.
- Connect the burning crater to the unit driving question: *Where does the energy in fossil fuels come from and where does it go?*
    - Now that you have mentioned fossil fuels (in the form of natural gas) as a source of energy for the burning gas crater, direct the conversation toward the driving question of where that energy comes from.
    - Explain that in order to answer the question and adequately share the answers with others, students will conduct a thorough investigation over the course of the unit.

2. Engage students to broadly consider the energy sources of different types of transportation.

- Distribute the *Energy Observations* handout to small groups of two to three students.
- Prompt students to brainstorm where the vehicles in the pictures get their energy and write their ideas on the line below each picture.
- Lead a class discussion for students to share their ideas for each vehicle. (Correct answers are that every vehicle shown runs on fossil fuels. It is not important that students identify the exact type of fossil fuels.)
- To segue into the next step, ask students where they think the energy and matter goes after being used in these ways.

3. Guide students through analyzing a graph and considering the impacts of atmospheric carbon dioxide.

- Display and discuss the *Atmospheric CO_2 at Mauna Loa Observatory* chart from the National Oceanic and Atmospheric Administration (NOAA) showing carbon dioxide in the atmosphere. Focus on the graph on the right side.
- Ask: *What do you think this graph is showing?*

    - Assist students in understanding the graph axes and what they represent. The chart shows the steadily increasing concentrations of carbon dioxide in the atmosphere (in parts per million) observed at NOAA's Mauna Loa Observatory over 60 years, beginning in 1959. The x-axis is the year and the y-axis shows parts per million of atmospheric carbon dioxide.

- Ask guiding questions to prompt students to share their ideas about what the graph means. Students may or may not know the answers at this point; the questions are intended to cue their thinking on carbon and to give you a sense of their prior knowledge on the topic. Ask:

    - *Do you think this increase in atmospheric carbon dioxide is the result of the energy use you explored in the* Energy Observation *handout? Why do you think carbon dioxide has increased in the Earth's atmosphere over the past 60 years?* (Correct response*:* Human activities like fossil fuel combustion, cement production, deforestation, and destruction of permafrost soils are adding carbon dioxide gas and other greenhouse gasses to the atmosphere.*)*
    - *Where do you think the carbon in the atmospheric carbon dioxide comes from? Is this the same thing that we saw coming out of the Darvaza gas crater?* (Correct responses may include: combustion of fossil fuels, gases emitted during volcanic eruptions, wildfires, and/or respiration of living organisms.)
    - *Do you think this increase in atmospheric carbon dioxide is helping and/or hurting the Earth's living things or both?* (Responses may include*:* increased atmospheric carbon dioxide is causing the average global temperature to increase, which in turn causes changes in regional climates. Living things may have difficulty adjusting to some of these changes, so in that sense, one could say the increase is "hurting" the planet. Increased carbon dioxide helps plants grow, so the rise in atmospheric carbon dioxide could be seen as "helping" the planet.)

- Record and display students' ideas (using chart paper, whiteboard, or a shared online document).

4. Display and discuss the photo *Putting the "Fossil" in Fossil Fuels*.

- Elicit students' ideas about how the photo connects to carbon and carbon dioxide by asking: *What do you think this photo is showing?*
    - Explain the setting of the photo if needed. (Coal, a fossil fuel, forms in seams underground. These are miners in a coal seam mining for coal. In the process, they discovered an ancient fossilized tree trunk.)
- Ask: *Given what you see in this photo, what do you think coal is made of?* (Correct response: Coal is formed from partially decayed and compacted plant matter.)
- Ask: *Where do you think the carbon in fossil fuels, like coal, ultimately comes from?* (Correct response: Since coal is made from plant matter, the carbon comes from the plant material.)
- Explain that coal is a fossil fuel, like the gas in the Darvaza gas crater, and is made of plant material that has partially decayed and been compacted over millions of years.

5. Introduce students to the lesson driving question and the culminating project that will anchor all learning objectives together.

- Tell students that they have now identified fossil fuels as a source of carbon and energy that can power things like cars, tractors, and factories. They have also learned that carbon in the form of carbon dioxide moves from fossil fuels into the atmosphere.
- Next, introduce the lesson driving question: *Where is Earth's carbon stored and how does it move among different reservoirs?* Explain to students that by investigating how different kinds of matter and energy move around our planet, they will learn to create a cohesive model that can be used to help others understand how the Earth works and how humans impact it. This first lesson will focus on tracking carbon in fossil fuels and beyond, and each subsequent lesson will dive deeper into the unit driving question: W*here does the energy in fossil fuels come from and where does it go*?
- Describe the culminating project for this unit. The class will be split into three teams, each researching a specific global matter and energy cycle (water cycle, rock cycle, photosynthesis, and respiration). Each team will create a model that illustrates how their assigned cycle works on Earth; each model should include a visual representation of the cycle, labels and arrows to show how it changes over time, and a paragraph describing why

that cycle is important on Earth. The three teams will then connect the models into a large whole-Earth model. Each team will prepare a presentation for the target audience to help them understand global matter and energy cycles.
- Opportunity for Action: Teams may have the opportunity to further inspire others to learn about matter and energy cycling on Earth by transforming their scientific model into an art piece for display in a local museum, science center, cafe, or the school.

6. Create a *Know & Need to Know* chart based on students' understanding and questions about fossil fuels.

- Ask: *What do you already know and what do you need to know about fossil fuels to help you thoroughly understand how fossil fuels fit into our global system of matter and energy cycling?*
- Create a class *Know & Need to Know* chart based on students' understanding and questions about fossil fuels.

    - Use the Think-Pair-Share process described below to elicit and record students' ideas and questions related to the unit, which can be revisited over time.
    - Ask students to think on their own and then discuss with a partner:

        - *What do we already know about fossil fuels?*
        - *What do we need to know about fossil fuels in order to create a thorough and accurate model of how energy moves through Earth's systems into and out of fossil fuels?*

    - Circulate as students work to help with guiding questions, such as:

        - *What are fossil fuels made of?*
        - *What kinds are there? How are they made?*
        - *How much of them do we have on Earth?*
        - *Where are they found?*
        - *How are they used by humans?*
        - *What impacts do our use of them have on the planet?*
        - *How are they useful to humans?*

    - Prompt students to share their ideas and questions in a class discussion, recording their thoughts on the class *Know & Need to Know* chart.

- Keep the chart in a visible place in the classroom or easily accessible online to reference students' expertise and questions from the beginning of the unit. Tell students that they will more formally revisit the chart throughout the unit as they learn new content and develop new questions.

Tip

Step 6: Consider providing sentence stems for the *Know & Need to Know* chart. For example:

"I know that _____, and I wonder if _____?"

Tip

Think-Pair-Share is a learning strategy where students work individually and collaboratively to enhance comprehension of the material. For some great tips on how to do an effective Think-Pair-Share activity, see *AdLit.org*.

Tip

You may also allow students to write their questions on sticky notes so that those who do not wish to share verbally can do so. They can put their notes on the board and you can collect and read them aloud as you move through the exercise.

Informal Assessment

Teachers will assess current and prior knowledge by looking over the *Know & Need to Know* chart that student pairs use to articulate their initial understanding about fossil fuels. This graphic organizer, along with offerings of ideas, allows the teacher to get an initial sense of prior knowledge and understanding in this topic area.

Extending the Learning

Extending Step 3: What causes the "wiggles" on the Keeling Curve? Use the graph of atmospheric carbon dioxide to have students consider the causes of annual fluctuations.

- Return to the *Atmospheric CO_2 at Mauna Loa Observatory* chart from NOAA showing carbon dioxide in the atmosphere. This time focus on the graph on the left. Ask students

why they think the wiggles on the graph are there and what could explain the fluctuations?

- Use a Think-Pair-Share strategy to give students a chance to posit thoughtful answers.
- Follow their initial thoughts by showing NASA's *A Year in the Life of Earth's CO_2* video.
- Explain that photosynthesis (which they will explore in depth later in the unit) removes carbon dioxide from the atmosphere. In spring and summer, when there is more vegetation throughout the Northern Hemisphere, photosynthesizing organisms take in more carbon dioxide. In the Northern Hemisphere's fall and winter, leaves fall from many trees and plants die, resulting in less carbon dioxide consumption overall.

OBJECTIVES

Subjects & Disciplines

Earth Science

Learning Objectives

Students will:

- Understand that average carbon dioxide levels in Earth's atmosphere have been increasing, on average, over the past 60 years.
- Articulate their initial ideas and generate questions related to fossil fuels and carbon.

Teaching Approach

- Project-based learning

Teaching Methods

- Brainstorming
- Discussions
- Information organization

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Information, Media, and Technology Skills
    - Information Literacy
    - Media Literacy
- Critical Thinking Skills
  - Analyzing
  - Remembering
  - Understanding
- Science and Engineering Practices
  - Analyzing and interpreting data
  - Asking questions (for science) and defining problems (for engineering)
  - Constructing explanations (for science) and designing solutions (for engineering)

National Standards, Principles, and Practices

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

• **CCSS.ELA-LITERACY.SL.7.1:**
Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on Grade 7 topics, texts, and issues, building on others' ideas and expressing their own clearly.

NEXT GENERATION SCIENCE STANDARDS

• **Crosscutting Concept 4:**
Systems and system models
• **Crosscutting Concept 5:**
Energy and matter: Flows, cycles, and conservation
• **ESS2.A: Earth Materials and Systems:**
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.

• **ESS3.C: Human Impacts on Earth Systems:**

Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth’s environments can have different impacts (negative and positive) for different living things.

• **MS-ESS2-1:**

Develop a model to describe the cycling of Earth’s materials and the flow of energy that drives this process.

• **Science and Engineering Practice 1:**

Asking questions and defining problems

Preparation

BACKGROUND & VOCABULARY

Background Information

Fossil fuel use is an important current issue as it plays a vital role in our global energy systems. Fossil fuels are formed predominantly from plant and animal material buried, preserved, and altered over time through the high pressure and temperatures of various geologic processes. Thus, the carbon in fossil fuels ultimately comes from plants and animals.

Humans burn fossil fuels primarily because they release high-quality, concentrated, usable energy, which has played a positive role in industrialization. However, carbon dioxide released into the atmosphere due to fossil fuel use has grown dramatically over the past 60 years of continuous measurement, and this has negative impacts on the global environment.

Prior Knowledge

["Students should be familiar with the fact that carbon is an element on the Periodic Table of Elements, and is an atom that bonds with other atoms to form various compounds."]

Recommended Prior Activities

- None

Vocabulary

Term	Part of Speech	Definition
carbon	*noun*	chemical element with the symbol C, which forms the basis of all known life.
carbon emission	*noun*	carbon compound (such as carbon dioxide) released into the atmosphere, often through human activity such as the burning of fossil fuels such as coal or gas.
coal seam	*noun*	coal deposit. Also called a coal bed.
combustion	*noun*	burning, or the process of a substance reacting with oxygen to produce heat and light.
emission	*noun*	discharge or release.
energy	*noun*	capacity to do work.
fossil fuel	*noun*	coal, oil, or natural gas. Fossil fuels formed from the remains of ancient plants and animals.
organic	*adjective*	composed of living or once-living material.
photosynthesis	*noun*	process by which plants turn water, sunlight, and carbon dioxide into water, oxygen, and simple sugars.

ACTIVITY 2: RESEARCHING FOSSIL FUELS | 50 MINS

DIRECTIONS

This activity is part of the Carbon Trackers unit.

1. Introduce the three types of fossil fuels.

- Remind students of the lesson driving question and their work in the *Putting the "Fossil" in Fossil Fuels* activity. Explain that in this activity they will conduct research on the different types of fossil fuels to better understand fossil fuels as a source of carbon and energy, and to answer their questions from the class *Know & Need to Know* chart.
    - If students identified oil and/or gas as fossil fuels in the *Putting the "Fossil" in Fossil Fuel* activity, reference their ideas and confirm that those and the other main types of fossil fuels will be explored in this activity.

- Distribute the *Fossil Fuels Classification Table* and explain that there are three main types of fossil fuels: petroleum (oil), coal, and natural gas.
- Go over the *Fossil Fuels Classification Table* with the class to be sure the students are clear on what each column is asking so they know what to look for in their reading.

2. Break students into teams and distribute materials for the jigsaw reading activity.

- Split the class into teams of three and have each team assign each member to a different type of fossil fuel. Each student is responsible for completing the table for their fossil fuel and then teaching the other two team members what they need to know to complete the table.
- Instruct all students to read the *Nonrenewable Resources* encyclopedic entry and add their initial ideas to the *Fossil Fuels Classification Table*.
- After this reading, direct each team member to read one of the following more in-depth encyclopedic entries about each type of fossil fuel and complete as much of their chart as possible from the readings:

    - *Coal*
    - *Natural Gas*
    - *Petroleum*

- Next, ask students to get into expert groups based on their assigned fossil fuel (one group for coal, one for natural gas, and one for petroleum).

    - Guide expert groups to work together to complete their section of the *Fossil Fuels Classification Table* before returning to their original group to share the information.

3. Direct student teams to share information from their individual readings to ensure that all team members can complete the *Fossil Fuels Classification Table*.

- Each student has five to seven minutes to share about their particular fossil fuel type with the other team members, helping their team to complete the *Fossil Fuels Classification Table*.
- Emphasize that while each student expert is sharing they are assuming the role of teacher and should explain thoroughly so that their team members have a solid understanding of each fossil fuel type. Encourage the rest of the team to not only take notes while the expert is sharing, but to also ask questions.

4. Lead a class discussion to review students' findings and revisit the class *Know & Need to Know* chart.

- Ask each team to contribute one to three major findings from their reading/research. If time permits, have each expert provide one piece of information about their fossil fuel to the whole class. If students hear anything they didn't capture on their chart, encourage them to do it now.
- Revisit the class *Know & Need to Know* chart. With the new ideas from this activity, students may be able to move some items from the "Need to Know" to the "Know" column. They also may have new questions to add about how to connect what they learned to the unit project. Update the chart accordingly.
- Have students discuss in their groups what could be changed on the *Know & Need to Know* chart and then make suggestions. Circulate to press students to explain ideas, quote the readings, and justify their suggestions. Students' major findings from today are likely to answer questions on the chart.

5. To quickly assess their basic understanding of fossil fuels, have students complete the *Basics of Fossil Fuels Kahoot!* quiz.

Modification

Step 2: If each student does not have access to a computer to read the encyclopedic entries, you may want to print them before class and provide paper copies.

If your students need additional support with reading comprehension and/or note-taking strategies, consider reading the encyclopedic entries aloud with them, modeling the way you would take notes, highlight, and add to the *Fossil Fuels Classification Table* as or after you read.

Tip

Step 3: To help students more efficiently share about their particular fossil fuel, consider setting a timer with a limit of four to five minutes per person.

Provide sentence stems on the board or at the table that show the kinds of questions students might ask. For example: “Which part of the reading did you find that in?” or “Can you explain that in a different way?”

Informal Assessment

Collect students’ *Fossil Fuels Classification Table* at the end of class and use their responses to check their understanding as a group. The *Fossil Fuels Classification Table Answer Key* is provided.

Students’ responses to the *Basics of Fossil Fuels Kahoot!* quiz can also be used as a formative assessment of their understanding of fossil fuels.

OBJECTIVES

Subjects & Disciplines

Earth Science

Learning Objectives

Students will:

- Understand that there are three main types of fossil fuels: petroleum (oil), coal, and natural gas.
- Evaluate the sources, extraction methods, types of human uses, environmental impacts, and benefits of each fossil fuel resource.
- Model how carbon moves from living things into fossil fuel sources and finally into the atmosphere as a result of human’s extracting and burning fossil fuels for energy.
- Describe the value of fossil fuels to human societies.
- Practice skills in reading comprehension, effective note-taking, and communicating information gleaned from readings with others.

Teaching Approach

- Project-based learning

Teaching Methods

- Cooperative learning
- Reading
- Research

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Information, Media, and Technology Skills
    - Information Literacy
    - Media Literacy
- 21st Century Themes
  - Environmental Literacy
  - Global Awareness
- Critical Thinking Skills
  - Remembering
  - Understanding
- Science and Engineering Practices
  - Obtaining, evaluating, and communicating information

National Standards, Principles, and Practices

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

• **CCSS.ELA-LITERACY.RST.6-8.2:**
Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.
• **CCSS.ELA-LITERACY.SL.7.2:**
Analyze the main ideas and supporting details presented in diverse media and formats (e.g., visually, quantitatively, orally) and explain how the ideas clarify a topic, text, or issue under study.

• **Crosscutting Concept 5:**
Energy and matter: Flows, cycles, and conservation
• **ESS2.A: Earth Materials and Systems:**
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.
• **ESS3.C: Human Impacts on Earth Systems:**
Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth’s environments can have different impacts (negative and positive) for different living things.
• **MS-ESS2-2:**
Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.
• **Science and Engineering Practice 8:**
Obtaining, evaluating, and communicating information.

Preparation

BACKGROUND & VOCABULARY

Background Information

Fossil fuels are formed over millions of years from buried organic materials altered by heat and pressure. The energy in fossil fuels ultimately came from the sun, was moved into organic matter via photosynthesis and then finally into fossil fuels. The carbon in fossil fuels originated in the atmosphere, moved into plant matter via photosynthesis, and then finally into fossil fuels. Because fossil fuels form over such long periods and are irreplaceable over a human’s lifetime, they are considered nonrenewable resources.

When fossil fuels are burned, they release usable energy. The costs of obtaining them compared to their caloric value have made them critically important to the global energy economy. However, fossil fuel combustion also releases toxic gases and carbon dioxide into the atmosphere. As the concentration of carbon dioxide and other greenhouse gases in the atmosphere increases, the average temperature of the Earth rises and this impacts global climate in different ways.

In addition to the environmental impacts of fossil fuel combustion, the extraction and processing of fossil fuels into usable energy can have negative impacts on people and the environment.

Prior Knowledge

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Recommended Prior Activities

- Putting the "Fossil" in Fossil Fuels

Vocabulary

Term	Part of Speech	Definition
coal	*noun*	dark, solid fossil fuel mined from the earth.
extraction	*noun*	process by which natural resources are extracted and removed from the earth.
natural gas	*noun*	type of fossil fuel made up mostly of the gas methane.
nonrenewable resource	*noun*	natural resource that exists in a limited supply.
petroleum	*noun*	fossil fuel formed from the remains of ancient organisms. Also called crude oil.

ACTIVITY 3: TRACKING DOWN THE CARBON | 1 HR 15 MINS

DIRECTIONS

This activity is part of the Carbon Trackers unit.

1. Engage students by asking, "*Where do you think the carbon is stored on Earth?*" before students sort objects into carbon and non-carbon categories.

- Divide students into pairs or groups of three and give each group a collection of 6-10 everyday objects.
    - Examples of objects include: a rock, bottle of water, piece of plastic, shell, feather, carbon dioxide in a can of soda (tell them to classify the bubbles, not the can), leaf, flower, a piece of cotton fabric, piece of coal or Vaseline or other fossil fuel-based product, a piece of limestone, chert, marble, and a piece of wood. You could also ask them in which category would their finger, foot, or other body part belong.
    - Instruct each group to take about 10 minutes to categorize the objects into two groups: those that contain carbon and those that don't contain carbon.
- As a class, have each group briefly share and justify what they put in each category. Record these on the board to note themes and items that groups agreed or disagreed on.
- Use this sharing/discussion to help students determine that nearly all the objects provided contain carbon. Explain that they will be digging more thoroughly into how carbon moves through these objects.
    - Define the carbon cycle: the series of processes by which carbon compounds are converted from one form to another in the environment. Explain that carbon is the basis of life on Earth and critically important to living and nonliving things, and also makes up all three fossil fuels.

2. Introduce the concept of systems thinking to students to prepare them for Step 3.

- Start by introducing the term "systems" (an entity composed of diverse, but interrelated parts that function as a complex whole) and help students understand two important terms related to systems: reservoirs and processes.
- Reservoirs are a place where matter or energy resides (synonyms: pool, stock, storage); processes are things that move matter or energy between reservoirs (synonyms: flux, flow, transfer).
- Illustrate a simple system on the board to show that reservoirs can be depicted as circles or squares, and processes can be shown as arrows between the reservoirs.

- An example could be an individual student's financial system. Use a circle or square labeled "Money in Wallet" to symbolize money and explain to students that is a reservoir. Ask students what processes would remove money. "Spending" is the process that removes money from the reservoir; draw an arrow labeled "Spending," pointing out from the reservoir.
- Ask for examples of reservoirs that money might go into. It could be anything they would spend money on. For example, if students want to buy ice cream, draw a square or circle labeled "Ice Cream Store" touching the tip of the "Spending" arrow.
- Ask what process might put money into the "Money in Wallet" reservoir. One answer might be "Earning," which would be illustrated as an arrow pointing to the "Money in Wallet" reservoir. Ask for examples of reservoirs that would be the source of the earned money (e.g., a job, a neighbor or parent that paid the student for a chore). Before moving to the next step, review again with students which parts of the example are processes and which are reservoirs.

3. Challenge students to create a simple model of the carbon cycle based on prior knowledge and activate thinking on this topic.

- Task each student pair or team to collaboratively identify the major reservoirs on Earth that all carbon objects come from: biosphere, lithosphere, hydrosphere, and atmosphere.
    - Distribute the *Cycle Diagram* handout or direct students to design their own on blank paper.
    - Instruct students to label each circle as a reservoir on Earth: biosphere, lithosphere, hydrosphere, and atmosphere. Guide students to write the label outside each circle to leave room inside the circles for other notes. Briefly explain what each term means and then connect each reservoir back to the objects sorted, showing which reservoir each object would come from.
- Ask students to brainstorm how carbon might move from one reservoir to another.
    - To help get them started, elicit a few initial ideas from the class. (Sample response: Burning coal moves carbon from rock into the atmosphere. This could be recorded on the chart as an arrow labeled "Burning," pointing from the lithosphere to the atmosphere.)
    - Have students, in the same pairs or teams, record their initial ideas on a piece of scratch paper first.

- When they have a clear set of one to three processes in and out of each reservoir, they should then record them on their *Cycle Diagram*.
- Ask them to draw arrows between the various reservoirs and label the arrows with the name of the process(es) that allows carbon to move from one form in one reservoir to another form in another reservoir.

4. Lead a class "Snowball Discussion" to refine students' models into a consensus model representing what the class knows currently and identify questions that require investigation.

- Students begin in pairs or teams of three, with their first draft of the *Cycle Diagram*. Set a timer to give them three minutes to decide if the cycle is as complete as possible, based on their current knowledge.
- When the time is up, the pair or team joins another pair or team, creating a larger group. Set a timer for five minutes for each pair or team to share their diagram with their new teammates, justifying their choices and responding to the other group's probing questions. Each team will edit their diagram as necessary, based on new information from their new teammates.
- After 10 minutes (five minutes for each team to present to their partner team), prompt groups to rotate to join with another group to repeat this ten-minute process, until all groups have met with each other.
- Direct the class to reconvene in one large group and distribute fresh *Cycle Diagram* handouts (or blank paper if students have generated their own models). Instruct the class to generate a second draft that represents their collective knowledge about the carbon cycle and highlight areas they need to learn more about. Frame this as an activity that requires everyone to share their ideas to create the strongest class consensus model.

    - Students should record their own and the classes' ideas from the Snowball Discussion on their paper while the teacher does the same on a projected diagram to ensure the whole group comes away with the same diagram.
    - Begin with recording the names of the four reservoirs: biosphere, lithosphere, hydrosphere, and atmosphere. If students have done so in their discussions, break these into more specific smaller reservoirs. For example, the biosphere could be broken into land plants, ocean plants, land animals, and ocean animals. Query students to see how they might break them down.
    - Ask student volunteers to share some of the processes that move carbon from one to another, building vocabulary by connecting the proper scientific terms to their responses. For example, replace "burning" with combustion. Present the correct

vocabulary in a way that confirms their ideas but gives them the scientific term, versus implying that their simpler term was incorrect. This process is intended to teach vocabulary through building on what they already understand. Processes include the words listed below, though students are not expected to know all of these at this point:

    - Respiration
    - Litter fall, decay, and decomposition
    - Soil respiration
    - Ocean-atmosphere exchange (dissolution and diffusion)
    - Photosynthesis or chemosynthesis
    - Sedimentation
    - Fossil fuel combustion
    - Forest burning
    - Volcanism
    - Decomposition and oxidation of soil
    - Rock weathering

- Now use guiding questions to highlight missing pieces or further "need to know" pieces. Remind students that there is a finite amount of carbon on Earth. The atoms are not created or destroyed via natural processes on Earth, only moved around, so there must be a way to cycle it from one reservoir to another to get the Earth in balance.

    - For example, if students don't have a process for moving carbon from the atmosphere to the ocean or back, ask them how that might happen. (Answer: This happens due to air-sea exchange where carbon dioxide gas is dissolved into seawater or released back into the atmosphere.) If no one knows, add a question mark there to flag that further class research is needed.

- Finish up this discussion by highlighting the question marks as "need to know" items that they will investigate further and asking if they know the names of any sub-cycles that move matter or energy around within or between reservoirs.

    - Although students may not have identified the exact names, highlight their ideas related to the hydrosphere-atmosphere cycle via the hydrologic cycle, the lithosphere cycle of the rock cycle, and the biosphere-atmosphere cycle of photosynthesis and respiration.

- Inform students that while there are many other important matter and energy cycles on Earth, this unit will focus on these three cycles along with the broader carbon cycle.
- They will explore the missing pieces in the *Matter and Energy Cycles Research* activity.

5. Use the *Cycle Diagram Quiz* to assess students' understanding of the main concepts covered in the *Tracking Carbon to Understand its Flow* lesson.

- Distribute the *Cycle Diagram Quiz* to each student. Students should complete this assessment individually, but they can use their model cycle diagram for help.

Tip

Step 2: *InTeGrate* is a great resource for information about teaching systems thinking.

Tip

Step 3: Allow students creative freedom in this step. Their models don't necessarily need to include circles; they could divide the paper into quadrants or any other creative way to show the four reservoirs that makes sense to them. The goal is to help them create an effective mental model. Let them try a free-form creative approach.

Note that the biosphere is not entirely based on land but also includes living things in the ocean, and that the hydrosphere is not entirely located in the ocean but also includes water on land and in the atmosphere.

Informal Assessment

Collect and review the *Cycle Diagram Quiz* to assess students' understanding of the main concepts covered in this lesson. The *Cycle Diagram Quiz Answer Key* is provided.

Extending the Learning

Useful readings to help students cement and expand their understandings about the topics discussed in this activity are the *Earth's Systems* article, and the *Carbon Cycle*, *Biosphere*, *Hydrosphere*, *Atmosphere*, and *Lithosphere* encyclopedic entries.

You could assign these readings as homework or use additional class time to include them.

OBJECTIVES

Subjects & Disciplines

Earth Science

Learning Objectives

Students will:

- Utilize the skill of information modeling to help determine their current understanding of a complex process and highlight remaining questions.
- Understand that Earth's systems can be represented in one way with four major reservoirs: the lithosphere, hydrosphere, biosphere, and the atmosphere.
- Understand that carbon moves through these reservoirs via many different processes.

Teaching Approach

- Project-based learning

Teaching Methods

- Brainstorming
- Discussions
- Inquiry

Skills Summary

This activity targets the following skills:

- 21st Century Themes
  - Environmental Literacy
  - Global Awareness

- Critical Thinking Skills
  - Applying
  - Creating
  - Evaluating
  - Remembering
  - Understanding
- Science and Engineering Practices
  - Developing and using models

National Standards, Principles, and Practices

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

• **CCSS.ELA-LITERACY.SL.7.1:**
Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on Grade 7 topics, texts, and issues, building on others' ideas and expressing their own clearly.

NEXT GENERATION SCIENCE STANDARDS

• **Crosscutting Concept 4:**
Systems and system models
• **Crosscutting Concept 5:**
Energy and matter: Flows, cycles, and conservation
• **ESS2.A: Earth Materials and Systems:**
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.
• **MS-ESS2-1:**
Develop a model to describe the cycling of Earth’s materials and the flow of energy that drives this process.
• **Science and Engineering Practice 1:**

Asking questions and defining problems

• **Science and Engineering Practice 2:**

Developing and using models

Preparation

BACKGROUND & VOCABULARY

Background Information

Carbon is one of the most abundant elements in the universe and, on Earth, it is contained in the biosphere, the atmosphere, the hydrosphere, and the lithosphere. Carbon moves through these four reservoirs in slow and fast cycles, and many Earth systems keep it all in balance, preventing too much carbon from being moved from one reservoir into another. This complex system is impacted by human activities, which in turn impacts the functioning of various systems on Earth, creating a feedback loop which alters the carbon cycle as well.

Prior Knowledge

["Students should be familiar with the fact that carbon is an element on the Periodic Table, an atom that bonds with other atoms to form various compounds.","Students should understand the law of conservation of matter and the idea that atoms and, in this case, carbon atoms are not created or destroyed on Earth under normal conditions. Thus the amount of carbon on Earth is finite."]

Recommended Prior Activities

- Putting the "Fossil" in Fossil Fuels
- Researching Fossil Fuels

Vocabulary

Term	Part of Speech	Definition
atmosphere	*noun*	layers of gases surrounding a planet or other celestial body.
biosphere	*noun*	part of the Earth where life exists.
carbon cycle	*noun*	series of processes in which carbon (C) atoms circulate through Earth's land, ocean, atmosphere, and interior.

Term	Part of Speech	Definition
hydrosphere	*noun*	all the Earth's water in the ground, on the surface, and in the air.
lithosphere	*noun*	outer, solid portion of the Earth. Also called the geosphere.
process	*noun*	continuous action, operation, or series of changes taking place in a defined manner.
reservoir	*noun*	large, concentrated supply or reserve.
system	*noun*	collection of items or organisms that are linked and related, functioning as a whole.

Informal Assessment

Cooperative Learning Group Interaction (Critical Thinking, Problem Solving, Communication, Teamwork)

The teacher, acting as a team facilitator when necessary, will informally assess students' cooperative learning skills as demonstrated within their pairs and/or small groups for the duration of the unit. Students will be evaluated based on their individual and group performance; that is, their ability to collaborate, listen attentively, and show willingness to take on various research and sharing roles as they investigate global matter and energy cycling.