EDC Earth Science

TEACHER EDITION

LAB-AIDS
Experiencing Science

The following pages are select samples from

EDC Earth Science

Included in this packet are sections from the *Teacher Edition* to be used in conjunction with the provided sample equipment and *Student Book* pages. We encourage the use of all provided sample materials in or out of a classroom to properly understand the seamless integration between equipment, student materials, and teacher resources.

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CONTENTS

CHAPTER FIVE

The Bigger Picture: Global Climate

Overview

In the previous chapter, students began their study of climate science by looking at their local climate and determining why it is different from other regions. They now broaden their focus and begin their exploration of factors that can cause Earth's global climate to change.

Climate is the area of Earth-systems science most frequently talked about in the media these days. Warnings that the human consumption of fossil fuels has triggered long-term climate change and stories about its initial effects—such as melting glaciers, droughts, and hurricanes—appear on TV and in newspapers and magazines almost daily. At the same time, climate science is one of the most complex areas of Earth science, and it is also a relatively young field. Climate science has brought together experts from many scientific disciplines. These authorities range from geologists, who understand the long-term changes in the configuration of Earth's continents and can read Earth's climate history in the rocks, to oceanographers, who understand the intricacies of the world's ocean currents, to meteorologists, who are adept at deciphering the complex workings of the atmosphere.

Climate scientists generally agree that global warming is occurring and that it corresponds with an increase in the concentration of carbon dioxide in the atmosphere from fossil-fuel combustion. Scientists have a broader range of ideas, however, about what the effects of this warming will be. This is because many factors influence climate globally and regionally. Computer models designed to predict the effects of global warming must incorporate accurate measurements of all these factors and also must address how changes in one factor will affect another. Thus, it is extremely difficult to predict specifically what will happen, and when, with Earth's climate.

Whether or not they pursue a career in science, today's students will be called on to make decisions about how to address climate change. They will be able to make more informed decisions if they understand the basic science behind climate predictions. In this chapter, students investigate some of the most important factors that influence climate globally. In Chapter 6, they will build their understanding by looking back into Earth's history and exploring times when climate has changed in the past.

Goals for Student Understanding

This table shows alignment of *Framework for K–12 Science Education* (the *Framework*) content, practices of science and engineering, and crosscutting concepts with chapter learning objectives. This is not intended to be used as a checklist, but it shows how students' learning experiences in *EDC Earth Science* map to the *Framework* goals.

Learning Objective	Framework Content, Practices, and Crosscutting Concepts	Where Taught
Students know that Earth's climate system is driven primarily by energy received from the Sun in the form of light energy, or electromagnetic radiation. Some of this energy is absorbed by the clouds and Earth's surface, and some is reflected back into space.	ESS2.D.1 Asking questions Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations Engaging in argument from evidence Obtaining, evaluating and communicating information Patterns Cause and effect Systems and system models Energy and Matter Stability and Change	*Reading*—"Following the Path of Light Energy" *Activity 1*—"The Greenhouse Effect" *Activity 2*—"The Albedo Effect"
Students know that most of the light energy that is absorbed by Earth's surface is reradiated as longer-wavelength heat energy. Certain gases in Earth's atmosphere, called greenhouse gases, trap the longer-wavelength heat energy, which warms Earth. Without this greenhouse effect, Earth would not be habitable.	ESS2.D.1 Asking questions Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations Engaging in argument from evidence. Obtaining, evaluating, and communicating information Systems and system models Cause and effect Energy and matter Stability and change	*Activity 1*—"The Greenhouse Effect"
Students know that the level of greenhouse gases in the atmosphere affects Earth's temperature. As the concentrations of these gases increase, Earth's average temperature increases.	ESS2.D.1 Asking questions Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations Engaging in argument from evidence. Obtaining, evaluating, and communicating information Systems and system models Cause and effect Energy and matter Stability and change	*Activity 1*—"The Greenhouse Effect"
Students know that another factor that influences Earth's temperature is the albedo effect. Albedo is a measure of the percentage of incoming light energy that is reflected. As Earth's albedo changes—the amount of heat energy absorbed versus reflected changes—the temperature at Earth's surface rises and falls. This causes regional, seasonal, and long-term global changes in Earth's temperature.	ESS2.D.1 Planning and carrying out investigations Analyzing and interpreting data Constructing explanations Engaging in argument from evidence. Obtaining, evaluating, and communicating information Patterns Cause and effect Systems and system models Energy and matter Stability and change	*Activity 2*—"The Albedo Effect"

Learning Objective	Framework Content, Practices, and Crosscutting Concepts	Where Taught
Students understand the major processes by which carbon moves from one reservoir to another in Earth's carbon cycle and how these processes affect the level of CO_2 in the atmosphere.	ESS2.D.1, ESS2.D.2 Developing and using models Planning and carrying out investigations Analyzing and interpreting data Constructing explanations Engaging in argument from evidence Obtaining, evaluating, and communicating information Cause and effect Systems and system models Energy and matter Structure and function Stability and change	*Activity 3*—"Moving Carbon Around" *Activity 4*—"Calling All Carbons"
Students understand that Earth's climate system is affected by negative and positive feedback loops. Negative feedbacks have a stabilizing effect and tend to keep conditions the same. Positive feedbacks are destabilizing and tend to accelerate changes in conditions.	ESS2.D.2 Developing and using models Constructing explanations Engaging in argument from evidence Obtaining, evaluating, and communicating information Cause and effect Systems and system models Stability and change	*Reading*—"The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops" *Address the Challenge*

Possible Misconceptions and Barriers to Learning

- Studies have shown that students tend to conceptualize complex, dynamic systems by considering the isolated behavior of components of that system but without understanding their interactions. They tend to want to identify a single causal force or a linear chain of events as responsible for the behavior of a system. An example of a linear chain of events in this case is recognizing that the burning of fossil fuels raises carbon dioxide levels in the atmosphere, which raises global temperatures. That linear chain does not account for how complex interacting factors, such as albedo and carbon sinks, may also affect global temperature.
- People commonly confuse two separate environmental issues associated with the atmosphere—the ozone hole and global warming. One misconception is that the hole in the ozone layer allows more heat to come through the atmosphere and warm Earth. This is not the case: the hole in the stratospheric ozone layer, which is the result of the release of human-made chemicals containing chlorine (CFCs) from refrigeration systems, air conditioners, and aerosols, does allow more ultraviolet radiation to reach Earth's surface, with cancer-causing effects. This hole does not, however, cause global warming (although ozone nearer to Earth's surface in the troposphere does act as a greenhouse gas).
- Climate change is a politically charged topic. As such, extreme views tend to be emphasized—either that global warming is a hoax or that global catastrophe is imminent. It is important to stay informed about current scientific developments in this area and be prepared to counter common misconceptions about the causes and implications of climate change. A number of websites offer current information, such as:
    - Global Climate Change: NASA's Eyes on Earth, at climate.jpl.nasa.gov/
    - Real Climate: Climate Science from Climate Scientists at realclimate.org/index.php/archives/2007/05/start-here/

Assessment Outcomes

Students should be able to

1. draw a diagram that shows what happens to light energy from the Sun, including how much of the Sun's energy is absorbed by the atmosphere and Earth's surface and how much is reflected back into space.
2. describe the composition of Earth's atmosphere and explain how greenhouse gases in the atmosphere affect Earth's energy balance and the temperature near Earth's surface.
3. design and carry out an experiment to measure the relative albedo of dark and light-colored surfaces, and relate this to the relative albedo of major surfaces on Earth. They should be able to predict how increases or decreases in the relative extent of these surfaces will affect Earth's temperature.
4. demonstrate through an experiment how carbon is transferred from one reservoir to another, describe all of the major processes by which CO_2 isadded to and subtracted from Earth's atmosphere, and predict how changes in flux rates between carbon reservoirs could change CO_2 levels in the atmosphere.
5. give examples of positive and negative feedback loops within Earth's climate system and describe their effects.

Assessment Strategies

Students have a number of opportunities in this chapter to show their initial and developing understanding of the nature and methods of Earth Science. By taking note of the answers given by students completing group work or working individually, you can determine pacing, identify which concepts need more or less emphasis, and gauge students' understanding of the content by the end of the chapter. The following table summarizes the formative and summative assessment opportunities.

The table also provides an alignment between the student assessment outcomes and the assessment items at the end of the chapter. You should determine ahead of time which of these assessment opportunities you will evaluate formally (assign a grade) and which you will evaluate more informally. In general, the *Consider* and *Investigate* sections provide opportunities for formative assessment, and the *Process* section provides opportunities for summative assessment.

Opportunities	Information Gathered
Consider	
Brainstorming	Students' prior experiences with the ocean and their understandings of ocean movements, the properties of ocean water, and the nature of ocean currents
What's the Story? "Washing Away"	Students' initial ideas about the forces that drive ocean currents and whether it would be possible for an ocean current to propel people on a raft across the Pacific Ocean
Investigate	
Reading—"Following the Path of Light Energy"	Assessment Outcome 1 (Assessment item 1)
Activity 1—"The Greenhouse Effect"	Assessment Outcome 2 (Assessment item 8)
Activity 2—"The Albedo Effect"	Assessment Outcome 3 (Assessment items 2–4)
Activity 3—"Moving Carbon Around"	Assessment Outcome 4 (Assessment items 5–7)
Activity 4—"Calling All Carbons"	Assessment Outcome 4 (Assessment items 5–7)
Reading—"The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops"	Assessment Outcome 5 (Assessment item 11)
Address the Challenge	Assessment Outcomes 1–5 (All assessment items)
Process	
Share	Students' abilities to communicate what they have learned about factors affecting global climate and construct an informed and convincing presentation regarding the causes and effects of climate change
Discuss	Students' abilities to recognize that the complex interactions in Earth's climate system make it difficult to predict specifically what will happen with climate over time in any specific place Students' abilities to relate all the climate concepts and factors they studied in this chapter and Chapter 4 in a concept map
Assessment	Students' understandings of the range of concepts presented throughout the chapter; these questions can be used in class, for homework, or as a quiz at the end of the chapter

Scope and Sequence

The following is provided to help with your lesson planning. Adjust it according to the needs and interests of your classroom, and whether you assign readings as homework or complete them in class.

WEEK			DAY		PREVIEW
1	**Consider**		1	Introduce chapter, and discuss *Brainstorming* questions	Students brainstorm about what they know from the media and previous science classes about climate change.
1	**Consider**		2	Read/discuss *What's the Story*—"Washing Away" Introduce *Challenge*	Students read the story, which describes a community in Kivalina, Alaska, that is feeling the effects of global warming and wondering what the future holds for its families and their homes.
1	**Investigate**	Gather Knowledge	3	Read/draw diagram/discuss *Reading*—"Following the Path of Light Energy"	Students use information in a reading to draw a diagram that shows what happens to the energy that is transmitted to Earth from the Sun. They also think about how the amount of light energy absorbed by Earth might vary from one region of Earth to another.
1			4	*Activity 1*—"The Greenhouse Effect"	Students learn about the greenhouse effect and study data to compare Earth's energy balance to that of Venus.
1			5	*Activity 2*—"The Albedo Effect" Part A: Studying Images of Earth	Students design and carry out an experiment to prove that light-colored surfaces reflect more light energy than dark surfaces and develop hypotheses about the relative albedo of various Earth surface materials based on images of Earth from space.
2			6	*Activity 2*—"Part B: Albedo Experiment"	
2			7	*Activity 2*—"Part B: Albedo Experiment"	
2			8	*Activity 3*—"Moving Carbon Around"	Students investigate in experiments and with molecular models how carbon atoms are transferred between rocks and the atmosphere.
2			9	*Activity 4*—"Calling All Carbons"	Students explore the carbon cycle by analyzing information about processes by which carbon is transferred from one reservoir to another.
2			10	*Reading*—"The Greenhouse Effect, the Carbon Cycle, and Feedback Loops"	Students read about feedback loops and think about how negative and positive feedback loops affect Earth's climate.
3		Address the Challenge	11	Prepare presentation for jury	Students prepare for a community meeting to discuss the future of Kivalina, Alaska.
3	**Process**		12	*Share*—Present arguments	
3			13	*Discuss*	
3	**Review**		14	*Review* (including concept map, part of *Discuss*)	
3	**Assessment**		15	*Summative Assessment*	

Materials and Preparation

Note: All reproducible pages (Student Sheets, Literacy Supplements, and Resource Supplements) and many images from the student book can be found in the Teacher Resources as PDFs or slide presentations.

You may choose to use the following optional Literacy Supplements:

- Literacy Supplement 5.1: *Science Fact Triangle* for "Following the Path of Light Energy"
- Literacy Supplement 5.2: *Science Fact Triangle* for "The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops"

Prior to *Activity 1*—"The Greenhouse Effect"

1. Gather the materials listed below.

FOR EACH GROUP OF STUDENTS

- 1 set of 11 Atmosphere Component Cards
- 1 set of 5 Greenhouse Effect Cards

FOR EACH STUDENT

- (optional) Resource Supplement 5.1: *History and Evolution of Earth's Atmosphere*

2. Keep the sets of Atmosphere Component Cards separate from the sets of Greenhouse Effect Cards because the Greenhouse Effect Cards are not given to students until Procedure Step 2 of the activity.

Prior to *Activity 2*—"The Albedo Effect"

1. Gather the materials listed below.

PART A
FOR THE TEACHER

- means of projecting* the images of Earth in Figures 5.5–5.7 (see Step 2 below)

PART B
FOR EACH GROUP OF STUDENTS

- 2 30-mL graduated cups
- 2 thermometers
- 1 timer (or access to a clock with a second hand*)
- supply of black sand
- supply of white sand
- access to sunlight (or lamp* with 100-watt bulb*)

FOR EACH STUDENT

- (optional) Resource Supplement 5.2: *Design Your Own Albedo Experiment*
- (optional) Resource Supplement 5.3: *Procedures for the Albedo Experiment*

*not included in LAB-AIDS equipment package

2. The images of Earth in Figures 5.5–5.7 can be displayed directly from the slide presentation for Chapter 5, or can be printed onto transparency film and used with an overhead projector.

3. (optional) If you prefer not to have students design their own investigation (see Facilitating the Activity section), a set of Procedure steps is included as Resource Supplement 5.3: *Procedures for the Albedo Experiment.*

Prior to *Activity 3*—"Moving Carbons Around"

1. Gather the materials listed below.

PARTS A AND C
FOR EACH TEAM OF STUDENTS

- 1 LAB-AIDS Molecular Modeling Set containing:
  - 1 calcium atom (green with 2 pegs)
  - 3 carbon atoms (black with 4 pegs)
  - 8 hydrogen atoms (white with 1 peg)
  - 10 oxygen atoms (red with 2 pegs)
  - 20 covalent bonds (white tubes)

PART B
FOR EACH GROUP OF STUDENTS

- 1 bottle of limewater ($Ca(OH)_2$)
- 1 clear plastic bottle with plug-style cap
- 1 small candle
- 1 foil square
- access to matches or lighter*

*not included in LAB-AIDS equipment package

Prior to *Activity 4*—"Calling All Carbons"

1. Gather the materials listed below.

FOR EACH GROUP OF STUDENTS

- 1 set of eight Carbon Cards
- (optional) access to resources* to conduct research about their assigned carbon-transfer process.
- (optional) materials* for students to use to create visuals for their presentations

*not included in LAB-AIDS equipment package

Prior to *Address the Challenge*

1. Gather the materials listed below.

FOR EACH GROUP OF STUDENTS:

- (optional) materials* for students to use to create visuals or models for their presentations

FOR THE TEACHER AND/OR EACH STUDENT

- (optional) Resource Supplement 5.4: *Climate Concept Map* (see Step 2 below)

*not included in LAB-AIDS equipment package

2. At the end of the chapter, students are asked to create a concept map and if desired, you can project and/or distribute copies of the sample map provided as Resource Supplement 5.4: *Climate Concept Map.*

3. Describe one of the surface materials that could change in extent so that it covers more or less of Earth's surface over time. Referring to the light energy path diagram you drew, how would you expect this change to affect Earth's average temperature? *Students may choose, for example, to focus on the extent of deserts. If deserts expand (replacing areas that previously had vegetation), that would increase Earth's overall albedo and tend to decrease Earth's temperature. If the extent of the polar ice caps shrinks, Earth's albedo would decrease and this would cause Earth's temperature to rise. Human activities and land use patterns change albedo, too. Students might think about how increases in the amount of paved area could affect albedo.*

4. Another factor influencing albedo is the angle at which sunlight strikes the surface. When light strikes at a lower angle, more is reflected. How does this factor affect the albedo of different parts of the globe? *This will increase the albedo of regions at higher latitudes (toward the poles) regardless of the surface material. This means that there are multiple factors that affect the albedo of a particular place.*

5. In the introductory story, residents of Kivalina have noticed that snow and ice cover the water near their island for shorter periods during the winter than in the past. Over time, how would you expect this reduction in snow and ice to affect the region's average albedo? How would you expect the change in albedo to affect the region's average temperature? *Students should recognize that a decrease in the amount of snow-and-ice cover over the course of a year would reduce the region's albedo and tend to increase the temperature.*

So now you know that the temperature near Earth's surface is related to whether energy is reflected into space or trapped by greenhouse gases such as CO_2. The more CO_2 in the atmosphere, the more heat will be trapped, and the more Earth's temperature will rise. So where does this CO_2 come from? Explore this in the next two activities.

ACTIVITY 3
Moving Carbon Around

Setting the Stage: Carbon in Earth's Systems

The element carbon is one of the essential components of every cell. Did you know that the carbon in your body has been around since before Earth formed 4.6 billion years ago? In fact, it formed in the center of a star that lived and died before Earth's Sun was formed.

Since the carbon in your body first formed, it has combined with other atoms and changed form many times. It has resided in various parts of Earth—the soil, the rocks, the oceans, living things, and the atmosphere. These parts of Earth's systems that contain carbon are also known as carbon reservoirs. Table 5.1 shows the approximate amount of carbon that resides in each of Earth's major carbon reservoirs.

Table 5.1: The Approximate Amount of Carbon in Earth's Major Carbon Reservoirs in Gigatons (1 gigaton = 1 billion tons)[2]

MAJOR CARBON RESERVOIR	APPROXIMATE AMOUNT OF CARBON (gigatons)
Vegetation	610
Soils	1,560
Atmosphere (preindustrial)	600
Ocean mixed layer*	1,000
Deep ocean	38,000
Sediments and rocks	66,000,000

*Ocean mixed layer: the shallower parts of the oceans where more mixing with air occurs.

The carbon moves in and out of some of these reservoirs (such as vegetation) relatively quickly. On the other hand, carbon typically is stored in other reservoirs—particularly rocks—for very long periods of time. The term *carbon flux* refers to the amount of carbon that is transferred from one reservoir to another during a given time period.

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How does a carbon atom get from rocks to the atmosphere? From water to rocks? In this next activity, you'll investigate the processes that move carbon atoms around.

Materials

PARTS A AND C
FOR EACH TEAM OF STUDENTS:

- 1 calcium atom (green)
- 3 carbon atoms (black)
- 8 hydrogen atoms (white)
- 10 oxygen atoms (red)
- 20 covalent bonds (white tubes)

PART B
FOR EACH GROUP OF STUDENTS:

- bottle of limewater, ($Ca(OH)_2$)
- wide mouth bottle with plug-style cap
- small candle
- foil square
- access to matches or lighter

ACTIVITY 3
Moving Carbon Around

This activity helps students understand how carbon atoms are transferred from one reservoir to another.

Facilitating *Activity 3*—"Moving Carbon Around"

- Form students into groups of four. (Parts A and C are done in pairs, Part B in a group of four.)
- Review Part A Procedure Steps with students, and, if needed, review chemical formulas and equations.
- Review the Part B Procedure, explain your expectations, and review safety precautions for using candles and matches.
- If desired, demonstrate proper techniques for capturing the combustion gases and adding them to the limewater.

  Note: An alternative to the method given in the Procedure is to place the bottle so that it completely surrounds the lit wick and wait until the flame goes out. While somewhat easier, this method adds smoke (and sometimes wax) to the bottle and can lead students to conclude that the smoke, not the CO_2, causes the cloudiness in the limewater.
- Distribute the molecular modeling sets, explain that students should work in pairs when using these (in both Parts A and C), and have them begin Part A.
- Circulate to each group, providing guidance when needed.
- As groups complete Part A, provide them with materials for Part B. Emphasize safety precautions.

Procedure

Record all observations and answers in your notebook as you work.

Part A: Modeling Combustion

1. Use the structural diagrams in Figure 5.8 and the molecular modeling pieces to create one molecule of propane (C_3H_8), a common fuel, and one molecule of oxygen gas (O_2).

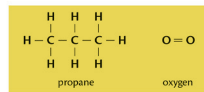

FIGURE 5.8
The molecular structure of propane and oxygen.

2. Model the combustion of propane by:
   a. Making 4 more O_2 models then putting any unused modeling pieces away.
   b. Modeling the breaking of the reactant bonds by removing all the white bonds from the atoms of all six reactant molecules (one C_3H_8 and five O_2).
   c. Modeling the formation of the products by reassembling all the bonds and atoms from the "broken" reactant molecules to make as many water (H_2O) and carbon dioxide (CO_2) molecules as you can.
3. Count up the number of H_2O and CO_2 molecules you made in Step 2 then complete the chemical equation below that shows the combustion of propane. Write the completed equation in your notebook.

$$C_3H_8 + 5O_2 \longrightarrow \_\_\_ CO_2 + \_\_\_ H_2O$$

Part B: Producing and Sequestering CO_2

4. Work in groups of 4. Obtain the Part B materials from your teacher.
5. Place the bottle cap upside down on the table and fill it almost completely up with limewater. Holding the bottle upside down, push it down firmly onto the cap. Then flip the capped bottle right side up. Observe and describe the limewater.
6. Gently shake the bottle 10 times then place it upright on the table. Observe the limewater and record changes, if any, to its appearance.
7. Uncap the bottle. Place the cap on the table and then carefully pour the limewater back into the cap. Place the cap with limewater somewhere safe because you will use it again in Step 10.
8. Place the candle in the center of the foil square as shown in Figure 5.9.
9. Carefully light the candle then hold the bottle upside-down so that the bottle-mouth is 2–5 cm (1–2 inches) over the candle flame. Hold it there for about 20–30 seconds to catch the combustion gases.
10. Keeping the bottle upside down, quickly, but carefully, move it over the

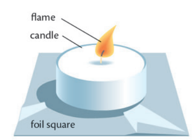

FIGURE 5.9
Setup for producing and sequestering CO_2 in Activity 3.

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- Continue to monitor each group, providing assistance as they complete Part B and move on to Part C.
- Have groups share their findings.
- Have each student complete the Analysis questions, and then discuss student responses as a class.

Responses to *Analysis* for *Activity 3*—"Moving Carbon Around"

1. The combustion of any hydrocarbon results in the production of the same two substances. Name these two substances. *Carbon dioxide (CO_2) and water (H_2O).*

2. What happens when CO_2 is mixed with limewater? Explain why you think this happens. *When mixed with CO_2, limewater turns cloudy. This happens because the CO_2 reacts with calcium hydroxide ($Ca(OH)_2$) in the limewater to produce calcium carbonate ($CaCO_3$), a solid precipitate that eventually settles out.*

3. CO_2 dissolves readily in seawater, which contains abundant Ca^{2+} ions. What do you think would happen to Earth's climate if a lot of CO_2 were to dissolve from the atmosphere into seawater? Explain why you think this would happen. *If a lot of CO_2 were to dissolve from the atmosphere into seawater, the CO_2 concentration in the atmosphere would decrease, and over time, this could result in less heat being trapped by the atmosphere and a lowering of the average surface temperature.*

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cap filled with limewater and push the bottle down firmly onto the cap.

11. Gently blow the candle out then flip the capped bottle right side up, gently shake it 10 times, and place it upright on the table. Observe the contents and record your observations.
12. Put the bottle someplace safe so it can sit undisturbed while you complete Part C.

Part C: Forming Limestone (working in pairs)

13. Use the structural diagrams in Figure 5.10 and the molecular modeling pieces to create one molecule of carbon dioxide (CO_2) and one molecule of calcium hydroxide ($Ca(OH)_2$). Put any unused modeling pieces away.

O = C = O	H – O – Ca – O – H
carbon dioxide	calcium hydroxide

FIGURE 5.10
The molecular structure of carbon dioxide and calcium hydroxide.

14. Limestone rock is made of calcite molecules ($CaCO_3$). To model limestone formation, remove all the white bonds from between all the atoms of the CO_2 and $Ca(OH)_2$ molecules.

    Reassemble all the bonds and atoms from the "broken" reactant molecules into a calcite molecule ($CaCO_3$) and a water molecule (H_2O).
15. Write down the chemical equation for the formation of limestone.
16. Observe the bottle of limewater again and record your observations.

Analysis

With your group, complete the following questions and record your answers in your notebook. Be prepared to share your answers with the rest of the class

1. The combustion of any hydrocarbon results in the production of the same two substances. Name these two substances.
2. What happens when CO_2 is mixed with limewater? Explain why you think this happens.
3. CO_2 dissolves readily in seawater, which contains abundant Ca^{2+} ions. What do you think would happen to Earth's climate if a lot of CO_2 were to dissolve from the atmosphere into seawater? Explain why you think this would happen.

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Carbon dioxide is an important greenhouse gas, and its concentration in the atmosphere is an important driver of climate change. What are the factors that can cause CO_2 levels in the atmosphere to rise? What processes in Earth's systems subtract CO_2 from the atmosphere? What types of human activities affect CO_2 levels in the atmosphere? In Activity 4, explore these questions.

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ACTIVITY 4

Calling All Carbons

This activity helps students understand the major processes by which CO_2 is added to and subtracted from Earth's atmosphere.

Facilitating *Activity 4*—"Calling All Carbons"

- Have students read Setting the Stage: The Carbon Cycle.
- Form students into groups of three or four and distribute one set of eight Carbon Cards to each group.
- Have them scan the cards, and point out that there are seven "process cards" and an eighth "General Information" card that summarizes the carbon cycle.
- Explain that each group member should read all eight cards and then discuss the information on the cards with the whole group. Emphasize that each student should complete his or her own Table 5.2 (and, if you want students to proceed without a class discussion/debriefing, the Analysis questions).

Teaching Strategies

Alternatively, you could assign a single card to each student and break the class into seven large groups with each group consisting of students with the same process card. Each group would consider the information on their process card and on the General Information card and then a representative(s) from each group would share their group's findings with the class.

ACTIVITY 4

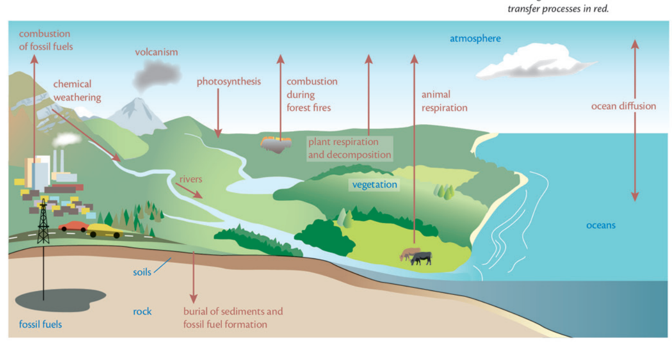
Calling All Carbons

Setting the Stage: The Carbon Cycle

The element carbon is critical to life on Earth. All living organisms contain many different and essential carbon-based molecules. Food is made from carbon-based molecules. Carbon dioxide (CO_2) is needed for plants to survive and if the atmosphere did not have any, the Earth would be much colder, perhaps too cold for living things to survive. However, too much CO_2 in the atmosphere could make the planet too hot for living things. Several Earth processes work together to cycle carbon from one carbon reservoir to another and to keep the amount in each reservoir stable. There are several major transfer processes that occur constantly that help carbon—most often in the form of CO_2—move from reservoir to reservoir. These carbon reservoirs and transfer processes work together to create Earth's carbon cycle. Because the actual carbon cycle is so vast and complex (it includes every plant, animal, microbe, ocean lake, river, puddle, soil, sediment, volcanic eruption, etc.), it is often simplified to show only the most important reservoirs and processes, as shown in Figure 5.11.

Because the amount of CO_2 in the atmosphere is so critical to Earth's climate, you will focus on how CO_2 is added to and subtracted from the atmosphere in this activity. Some processes add CO_2 to the atmosphere and are called CO_2 sources; other processes remove CO_2 from the atmosphere and store it in various places called carbon sinks. This movement of carbon from one reservoir to another is called the **carbon flux** and when properly balanced, it keeps the amount of carbon in each place relatively constant. This helps maintain stable conditions in Earth's biosphere, hydrosphere, atmosphere, and geosphere.

FIGURE 5.11
Simplified diagram of the carbon cycle, showing reservoirs in blue and carbon transfer processes in red.



- Briefly review/clarify any student questions or comments.
- Circulate to each group, providing guidance when needed.
- Have groups share their findings. Encourage each student to revise/complete his or her answers based on the discussion.
- Have students write answers to the Analysis questions in their notebooks, and then discuss them as a class.

Procedure

Record all observations and answers in your notebook as you work.

1. With your group, study the information on all 8 Carbon Cards and make sure everyone in your group knows the name of each process and understands how the process works. You might do this by splitting up the cards and explaining the processes to each other.
2. Sort the 7 Carbon Transfer Process Cards into groups, based on whether each process is a CO_2 source or contributes to a carbon sink. Record your results.
3. Sort the cards within each group (sources and sinks), in order from highest annual carbon flux to lowest carbon flux. Record your results.
4. Summarize your findings by drawing a table in your notebook with seven rows beneath the headings shown in Table 5.2 below. Then fill in the information.

Table 5.2

NAME OF PROCESS	HOW PROCESS WORKS	SOURCE OR SINK	ANNUAL CARBON FLUX

5. Write answers to the Analysis questions in your notebook. Be prepared to discuss them with the class.

Materials

FOR EACH GROUP OF STUDENTS

- set of 8 Carbon Cards

Carbon Transfer Process: Chemical Weathering of Rocks

NET EFFECT: *removes CO_2 from the atmosphere and stores it in the ocean*

CARBON FLUX: *0.1 billion metric tons/year*

Rainwater (H_2) and carbon dioxide (CO_2) from the atmosphere combine in soil and rock crevices on the land to form a weak acid called carbonic acid (H_2CO_3). This carbonic acid weathers and chemically breaks down the rocks, as shown in Figure 5.12, and rainwater washes away dissolved ions. These ions are carried by rivers to the sea where some of them (Si^{+4}, Ca^{+2}, and $C0_3^{-2}$) are taken up in the growing shells of microorganisms ($CaCO_3$ and SiO_2). These shells settle to the bottom of the ocean when they die. The net effect of this entire multistep process is that CO_2 is removed from the atmosphere and stored in the shells of organisms. A generalized chemical equation for this process is

$$\underset{\text{rocks}}{CaSiO_3} + \underset{\text{from the atmosphere}}{CO_2} \longrightarrow \underset{\text{calcite in shells}}{CaCO_6} + \underset{\text{quartz dissolved in seawater or incorporated into shells}}{SiO_2}$$

Sample Student Answers for Table 5.2

NAME OF PROCESS	HOW PROCESS WORKS	SOURCE OF SINK	ANNUAL CARBON FLUX
Chemical weathering of rocks	*CO_2 and water from the atmosphere combine to form carbonic acid, which chemically breaks down exposed rocks. Ions from the carbonic acid and the rocks are carried to the ocean by rivers and incorporated into the shells of marine organisms.*	*CO_2 is subtracted from the atmosphere*	*0.1 billion metric tons*
Volcanism associated with plate tectonic processes	*Volcanoes along plate tectonic boundaries (seafloor spreading centers and subduction zones) release CO_2 that was originally stored in rocks into the atmosphere.*	*CO_2 is added to the atmosphere*	*0.2 billion metric tons*
Formation of fossil fuels	*Sometimes the organic remains of plants and animals, which contain carbon, are preserved in oxygen-poor environments. Over long periods of time they accumulate, are buried, and incorporated into rock. Heat and pressure transform the organic material into oil, natural gas, and coal.*	*CO_2 is subtracted from the atmosphere*	*<1 billion metric tons*
Combustion of fossil fuels	*Fossil fuels—oil, natural gas, and coal—are extracted from Earth and burned, releasing CO_2 into the atmosphere.*	*CO_2 is added to the atmosphere*	*5 billion metric tons*
Photosynthesis	*Plants take in CO_2 from the atmosphere and produce carbohydrates, some of which are incorporated into plant tissue.*	*CO_2 is subtracted from the atmosphere*	*102 billion metric tons*
Respiration and decomposition	*Plants and animals break down carbohydrate molecules to obtain energy. During this process CO_2 is released.*	*CO_2 is added to the atmosphere*	*100 billion metric tons*
Diffusion of CO_2 into oceans, outgassing of CO_2 from ocean	*CO_2 from the atmosphere dissolves into ocean water, and dissolved CO_2 outgases from the ocean into the atmosphere. Cold water can hold more CO_2. As ocean water warms, it tends to release CO_2 into the atmosphere.*	*Depends on temperature of the ocean*	*Approx. 92 billion metric tons subtracted from atmosphere; 90 billion metric tons added to atmosphere*

Carbon Transfer Process: Volcanism Associated with Tectonic Plate Processes

NET EFFECT: *adds CO_2 to the atmosphere that was previously stored in rocks*

CARBON FLUX: *0.2 billion metric tons/year*

Rocks of Earth's crust containing carbon are recycled by tectonic plate processes. This carbon is released in the form of CO_2 when the rocks are melted, and the gas separates out and is erupted from volcanoes, such as the one shown in Figure 5.13. These volcanoes most commonly occur near plate boundaries, along subduction zones and seafloor spreading ridges. The net effect of this process is that carbon stored in rocks is released in the form of CO_2 to the atmosphere.

FIGURE 5.13
Mount St. Helens.

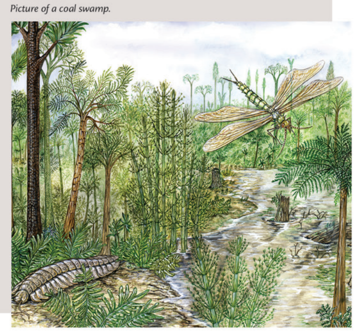
Carbon Transfer Process: Formation of Fossil Fuels

NET EFFECT: *CO_2 is removed from the atmosphere and incorporated into rocks*

CARBON FLUX: *< 1 billion metric tons/year*

Usually, when living things die, they decompose, releasing the carbon from which they are built to the atmosphere. In some (rare) cases, these organic remains are instead preserved in an oxygen-poor environment such as the bottom of certain ocean basins or in stagnant swamps such as the coal swamp in Figure 5.14. These remains accumulate and, over millions of years, are buried and incorporated into rock. Heat and pressure transform the preserved organic material into oil, natural gas, and coal. Oil and natural gas form primarily from the remains of microscopic marine organisms. Coal forms from land plants. It is estimated that approximately 100 tons of ancient life is converted to 1 gallon of gasoline. The net effect is to store carbon in the rocks of Earth.

FIGURE 5.14
Picture of a coal swamp.



Carbon Transfer Process: Combustion of Fossil Fuels and Other Organic Matter (such as wood)

NET EFFECT: *CO_2 that was stored in rocks is added to the atmosphere*

CARBON FLUX: *5 billion metric tons/year*

When fossil fuels such as oil, natural gas, and coal are extracted from Earth and burned (combusted), carbon and hydrogen in the fuel reacts with oxygen from the air to form CO_2, water, and heat. The CO_2, water vapor, and other by-products are released to the air through smokestacks such as the ones at the coal-burning power plant in Figure 5.15. The heat may be transformed into electricity and transported to people's homes and businesses for power, or may be transformed into mechanical energy in cars, trucks, or other vehicles. When wood or other organic material is burned, it also releases CO_2. The net effect of the combustion of fossil fuels and other organic materials is to release CO_2 into the atmosphere.

FIGURE 5.15
Coal-burning power plant.

Carbon Transfer Process: Photosynthesis

NET EFFECT: *removes CO_2 from the atmosphere and stores it in plants*

CARBON FLUX: *102 billion metric tons/year*

Plants such as the one in Figure 5.16 remove CO_2 from the atmosphere and store it. Photosynthesis uses CO_2 from the atmosphere, energy from the Sun, and water to produce carbohydrates (sugar) and oxygen. Light energy from the Sun is stored in the chemical bonds of the sugar molecule. Some of these carbohydrates are incorporated into plant tissue, where they are stored. The net effect of this process is that CO_2 is removed from the atmosphere and stored in the tissue of plants. A generalized chemical equation for the process of photosynthesis is

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6\ (\text{sugar}) + 6O_2$$

FIGURE 5.16:
Plants use CO_2, water, and energy from the Sun during photosynthesis.

Responses to *Analysis* for *Activity 4*—"Calling All Carbons"

1. List Earth's major carbon reservoirs. *Atmosphere, oceans, plants, soil, fossil fuels, crust (rocks), and buried sediments.*

2. Describe a process that has the net effect of removing carbon from the atmosphere. *Answers will vary. The processes that remove carbon from the atmosphere are: chemical weathering, formation of fossil fuels, and photosynthesis.*

3. Describe a process that has the net effect of adding carbon to the atmosphere. *Answers will vary. The processes that add carbon to the atmosphere are: volcanism, combustion of fossil fuels and other organic matter, respiration, and decomposition.*

4. Describe a process that both adds carbon to and subtracts carbon from the atmosphere. *Diffusion of carbon dioxide into and out of the oceans can either add or subtract CO_2 because cold seawater tends to absorb CO_2 from the atmosphere and warm seawater tends to release CO_2 to the atmosphere.*

5. During the 19th century, much of the forested land area in the eastern United States was cleared for agriculture. What effect would you expect this to have on CO_2 levels in the atmosphere? Explain your thinking. *This probably increased atmospheric CO_2 levels because photosynthesis by trees, which removes CO_2, would be reduced (unless it was exactly matched by plants that took the trees' place).*

CHAPTER 5 • THE BIGGER PICTURE: GLOBAL CLIMATE

Carbon Transfer Process: Respiration and Decomposition

NET EFFECT: *removes carbon from plants and adds CO_2 to the atmosphere*

CARBON FLUX: *100 billion metric tons/year*

Respiration (the reverse of photosynthesis) involves the breakdown of sugar using oxygen to obtain energy and building blocks to form new biomolecules. These reactions release CO_2, water, and energy as products and byproducts. Respiration occurs in both plants and animals, such as the dog in Figure 5.17. Another important way that CO_2 is added to the atmosphere is decomposition. When organisms decompose, they are consumed mostly by bacteria and fungi, and CO_2 is released. The net effect of respiration and decomposition is carbon stored in carbohydrates within plants and animals is released into the atmosphere in the form of CO_2. A generalized chemical equation for the process of respiration is

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2$

FIGURE 5.17
The dog's exhaled breath contains nearly a thousand times more carbon dioxide than is present in the air it inhales.

Carbon Transfer Process: Diffusion of Carbon Dioxide Into and Out of the Ocean

NET EFFECT: *variable; depends on temperature of ocean*

CARBON FLUX: *~ 92 billion metric tons/year from atmosphere into ocean; 90 billion metric tons/year from ocean into atmosphere*

There is a certain amount of CO_2 that can be dissolved in seawater. That amount depends on the temperature of the water. Cold water can hold more CO_2 than warm water, so cold seawater tends to absorb CO_2 from the atmosphere. Warmer water has higher kinetic energy. This higher kinetic energy increases molecular motion, which breaks intermolecular bonds and causes gases to escape from the solution. Therefore, warm seawater tends to release CO_2 to the atmosphere. So the net effect of the oceans on atmospheric CO_2 varies with the ocean temperature, as shown in Figure 5.18. Higher latitude oceans tend to remove more CO_2 from the atmosphere than they release (although as the water warms, this balance can change), and tropical oceans tend to release more CO_2 to the atmosphere than they take up.

FIGURE 5.18
Sea surface temperature: The orange areas are the highest temperatures and the dark blue areas are the lowest.

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Also the trees might have been burned, which would add CO_2 to the atmosphere.

6. If a large volcanic eruption were to occur somewhere on Earth, how would you expect this to affect CO_2 levels in the atmosphere? *This would increase atmospheric CO_2 levels because volcanic gases add CO_2 to the atmosphere.*

7. Compare the carbon flux rates of the various carbon transfer processes. Which processes absorb or release CO_2 at a lower rate, and which processes have a higher yearly flux rate? *Slower acting processes include fossil-fuel formation, chemical weathering, and diffusion. Faster acting processes include photosynthesis, combustion, and respiration/decomposition. Volcanic eruptions are hard to classify because the actual release of CO_2 happens quickly, but the time between eruptions is typically fairly long.*

8. Scientists have related the increased use of fossil fuels by humans to the warming of Earth's atmosphere that is occurring. Using data from the Carbon Cards and what you've

learned about the greenhouse effect, explain how increases in fossil-fuel use could cause the climate to warm. *Students should understand that the burning of fossil fuels is transferring carbon that was stored in rocks to the atmosphere at a much higher rate than atmospheric carbon is stored in rocks. The net effect of this is that the amount of carbon dioxide in the atmosphere increases over time. As the concentration of this greenhouse gas increases, the atmosphere absorbs and reradiates more heat energy back toward Earth's surface.*

9. Energy can also be produced from biomass, such as corn and sugar cane, and proponents of biofuels say this is a better alternative than fossil fuels. Based on what you know about the carbon cycle, what do you think of this idea? *Opinions will vary, but students should mention that (not taking into account CO_2 transfers associated with energy used for production and transportation) biomass fuels are "carbon neutral" because growing the plants removes the same amount of CO_2 as burning them releases.*

10. Describe and explain other natural events and processes or human activities that could affect CO_2 levels in the atmosphere. *Answers will vary. Students typically have difficulty coming up with any natural processes. Some students will describe such human activities as cigarette smoking, production/use of dry ice, and production/use of CO_2 cartridges (for various purposes.)*

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Analysis

Complete the following questions and record your answers in your notebook. Be prepared to share your answers with the rest of the class.

1. List Earth's major carbon reservoirs.
2. Describe a process that has the net effect of removing carbon from the atmosphere.
3. Describe a process that has the net effect of adding carbon to the atmosphere.
4. Describe a process that both adds carbon to and subtracts carbon from the atmosphere.
5. During the 19th century, much of the forested land area in the eastern United States was cleared for agriculture. What effect would you expect this to have on CO_2 levels in the atmosphere? Explain your thinking.
6. If a large volcanic eruption were to occur somewhere on Earth, how would you expect this to affect CO_2 levels in the atmosphere?
7. Compare the carbon flux rates of the various carbon transfer processes. Which processes absorb or release CO_2 at a lower rate, and which processes have a higher yearly flux rate?
8. Scientists have related the increased use of fossil fuels by humans to the warming of Earth's atmosphere that is occurring. Using data from the Carbon Cards and what you've learned about the greenhouse effect, explain how increases in fossil-fuel use could cause the climate to warm.
9. Energy can also be produced from biomass, such as corn and sugar cane, and proponents of biofuels say this is a better alternative than fossil fuels. Based on what you know about the carbon cycle, what do you think of this idea?
10. Describe and explain other natural events and processes or human activities that could affect CO_2 levels in the atmosphere.

By now you should understand that, although there's a clear link between CO_2 levels and Earth's temperature, there are many other factors that need to be considered. This next reading discusses how Earth's systems can interact to either stabilize the climate or accelerate climate change.

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Science Background

William F. Ruddiman, in his 2005 book, *Plows, Plagues and Petroleum,* suggests that in the past few millennia of human history, CO_2 levels have periodically dropped and slight cooling has occurred following periods of mass die-offs (e.g., the bubonic plague) as a result of less agricultural activity that allowed the regrowth of forests.

Facilitating the Discussion

As you discuss the various scenarios in the Analysis questions that add or subtract CO_2 to or from the atmosphere, encourage students to think about how each change might affect other aspects of Earth's climate system. An example would be the large volcanic eruptions that add CO_2 to the atmosphere but don't necessarily lead to warming because of the increased albedo effect. The more connections students can draw, the easier it will be for them to appreciate the complexity of this dynamic system.

READING

The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops

This reading describes how positive and negative feedback loops affect Earth's climate system. After students have completed this reading and written answers to the questions that follow, discuss them as a class.

Science Background

Cement Production

Cement production involves heating up limestone ($CaCO_3$) in a kiln. This process transforms the limestone rock into quicklime (CaO) and produces CO_2 as a by-product.

Science Background

Potential Impacts of Rapid Warming

Scientists have suggested that if the climate warms rapidly, shifts in climate zones and mass die-offs of vegetation could occur. This could increase CO_2 input to the atmosphere.

READING

The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops

Since the mid-1800s, when fossil-fuel burning began in earnest, CO_2 emissions have significantly increased (Figure 5.19). When CO_2 levels rise in the atmosphere, Earth's surface warms, and this warming has a variety of effects within Earth's systems. Some effects can actually accelerate the warming, making the climate change even faster. Other effects can reduce or reverse the warming trend and stabilize the climate.

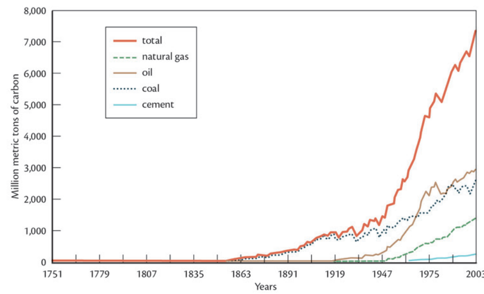

FIGURE 5.19
Global CO_2 emissions from fossil fuel use and cement production between 1751 and 2003.

When the concentration of greenhouse gases in the atmosphere causes more heat to be retained, the warmer temperatures decrease the amount of snow and ice cover in arctic regions, and this can initiate a **positive feedback loop** (a feedback that tends to accelerate change), as shown in Figure 5.20. From your work in Activity 2, you know that decreases in snow and ice cover lower Earth's albedo. When more heat is absorbed rather than reflected by the surface of Earth, this tends to increase the temperature of the atmosphere even more. The warmer temperatures mean that more snow and ice melts, lowering the albedo and raising the temperature even more, and so on. These types of positive feedback loops accelerate the warming trend—particularly as the amount of snow and ice decreases and forests expand northward over significant portions of the globe.

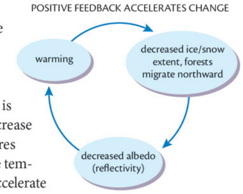

FIGURE 5.20
As warming temperatures decrease snow and ice cover in northern latitudes, this initiates a positive feedback loop and accelerates the warming trend.

Another type of feedback loop also occurs in Earth's system: a **negative feedback loop,** which tends to stabilize systems, keeping them from changing. An example of a negative feedback in Earth's climate system would be when warming temperatures lead to increased evaporation of water. If this evaporation leads to the formation of certain types of clouds—generally low clouds—

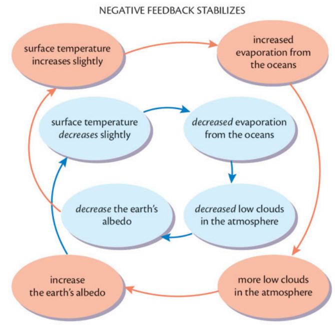

FIGURE 5.21
The warming of Earth's surface can increase evaporation rates, initiating a negative feedback loop and stabilizing Earth's climate.

the clouds tend to reflect more of the light energy from the Sun, cooling Earth's surface and stabilizing the climate, as shown above in Figure 5.21.

However, the behavior of Earth's climate system is not simple and easy to predict. Remember, that water vapor is a potent greenhouse gas and tends to trap heat energy radiating from Earth's surface. Therefore, increased rates of evaporation can also initiate a positive feedback loop, accelerating the rate of global warming. Scientists have found evidence that this type of positive feedback loop was responsible for the extremely hot conditions that exist today on Venus (although they don't expect anything so extreme to happen on Earth). Venus may have been partially covered with water (like Earth) early in the history of the solar system. Because it was a bit closer to the Sun, more of this water evaporated into the atmosphere. The water vapor in the atmosphere acted as a greenhouse gas, warming the planet even more, which evaporated more water into the atmosphere. This positive feedback loop eventually warmed the surface so much that all of the surface water boiled away. The water vapor in the atmosphere was broken apart by sunlight and the hydrogen escaped into space, so water can't form again. As you know from your work with the Carbon Cards in Activity 2, water plays a critical role in storing CO_2 in carbon sinks (in the ocean and in rocks). Without water to serve this role, CO_2 built up to extremely high levels in Venus's atmosphere.

Many other factors make it difficult to understand exactly what is happening and what is in store for Earth's climate. For example, fossil-fuel burning is also a major source of tiny airborne particles called aerosols. These aerosols have greatly increased in the lower part of Earth's atmosphere since the Industrial Revolution began in the mid-1800s. The aerosols increase the albedo of the atmosphere and tend to have a cooling effect on Earth's surface. Just how much of an effect these aerosols have is complicated to figure out, because the aerosols are difficult to measure. They vary in size and composition, are distributed unevenly in the atmosphere, and are added to and washed out of the atmosphere in a matter of days.

Responses to *About the Reading* for "The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops"

1. Give an example of a positive feedback loop and a negative feedback loop from everyday life. Explain how these feedback loops tend to stabilize or change the conditions. *Answers will vary. One possible example would be to relate positive and negative feedback loops to interactions between people. One person starts to raise his voice, which causes the other to raise her voice louder, and so forth as the fight escalates in a positive feedback loop. If, on the other hand, something said by one person calms the other, it acts as negative feedback (not the same as an insult!) and prevents the fight from escalating.*

2. Scientists have determined that large amounts of carbon dioxide, and other greenhouse gases, such as methane, are locked away in frozen ground (permafrost) in arctic regions. As the climate warms, these greenhouse gases are released to the atmosphere. What type of feedback loop (positive or negative) would you expect from release of these gases? Explain your thinking. *Students should recognize that the release of greenhouse gases from the ground into the atmosphere would act as a positive feedback loop, causing the climate to warm even more and melt more of the permafrost. They might be interested to know that scientists have estimated approximately 14% of the world's carbon is locked up in arctic permafrost.*

3. Describe some factors that make it difficult to predict the future of Earth's climate. *Students should recognize that the many positive and negative feedbacks in Earth's climate system make it difficult to predict just how much warming will occur as a result of increasing CO_2 levels from fossil-fuel burning. Also, although the increased CO_2 levels are expected to raise average global temperatures, the effects on specific regions will vary. This is because (as they know from Chapter 4) many factors make each part of the world unique and influence regional climates.*

CHAPTER 5 • THE BIGGER PICTURE: GLOBAL CLIMATE

About the Reading

Write your responses to the following questions in your notebook. Be prepared to discuss your answers with the rest of the class.

1. Give an example of a positive feedback loop and a negative feedback loop from everyday life. Explain how these feedback loops tend to stabilize or change the conditions.
2. Scientists have determined that large amounts of carbon dioxide, and other greenhouse gases, such as methane, are locked in frozen ground (permafrost) in arctic regions. As the climate warms, these greenhouse gases are released to the atmosphere. What type of feedback loop (positive or negative) would you expect from release of these gases? Explain your thinking.
3. Describe some factors that make it difficult to predict the future of Earth's climate.

• • • • • • •

Now, pull together what you have learned about Earth's climate and the factors that cause climate to change. Prepare to play the role of a resident of Kivalina, participating in a public meeting in your community.

ADDRESS THE CHALLENGE

The citizens of Kivalina have called a public meeting to discuss what is happening to their community. They are trying to understand why the climate is changing and make some decisions about what they will do about it.

Members of the community are coming to the meeting with some opinions already formed. Generally, their thinking falls into three categories:

1. "We need to move! Our climate is changing because humans are burning more fossil fuels, and with less ice on the ocean, more heat will be absorbed and it will get even worse. We need to start looking for another home, off the island."
2. "Don't worry, we can stay—all will be fine. Our climate has been changing lately, but this is just temporary. The Earth will take care of us—whenever one thing changes, something else happens to bring it back into balance. I think we should just try to hold the sea back by building walls until the situation returns to normal."
3. "Let's wait a little longer to make a decision. The climate is complicated, and even if the global temperature is warming, we can't know what will actually happen in our community in the future. We should wait awhile longer and see what actually happens before we make a decision."

Now, prepare to attend the public meeting, representing one of the three viewpoints above. Join with others representing the same viewpoint, and get ready to convince your neighbors that your opinion is well founded. To make sure your group is ready, pull together your arguments and evidence, and prepare a written summary. Regardless of what you recommend, your written

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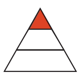
LITERACY SUPPLEMENT 5.2

Respones to *Science Fact Triangle* for "The Greenhouse Effect, the Albedo Effect, the Carbon Cycle and Feedback Loops"



TOP LEVEL

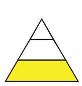
Positive feedback loops accelerate change, and negative feedback loops tend to stabilize systems. Positive feedback loops could accelerate the accumulation of carbon dioxide in the atmosphere and cause the climate to warm more rapidly. Negative feedback loops could reduce the amount of carbon dioxide that accumulates and reduce climate effects. The complex feedback loops in Earth's climate system, make it difficult to predict the specific behavior of Earth's climate.

MIDDLE LEVEL

As warmer global temperatures lead to a reduction in polar ice fields, less solar radiation is reflected back into space, and more is absorbed by Earth's surface. This is a positive feedback loop that accelerates change.

An example of a negative feedback loop is seen when warming temperatures lead to increased cloud formation, which increases the reflection of solar energy back into space, and reduces the amount of solar energy that strikes the surface of Earth.

Burning fossil fuels leads to particulate matter called aerosols, which tend to have a cooling effect on Earth. However, these aerosols don't stay long in the atmosphere.



BOTTOM LEVEL

When carbon dioxide levels rise in the atmosphere, Earth's surface warms.

Water vapor is a potent greenhouse gas and can also trap heat, leading to an increase in surface temperatures, as is what is thought to have happened on Venus.

ADDRESS THE CHALLENGE

Have students work in groups of 3 or 4. You can decide whether you want to allow the groups to select one of the three positions, or assign them to make sure each position is represented. If you assign positions, you may want to say to students that you recognize that the position students are assigned may not represent how they feel personally; however, they should be able to envision the arguments that would be presented by any of the groups. This will help them to clarify their own understanding of climate science.

Each group should prepare a written summary and presentation of the science that supports their position. Emphasize to them that it is important to anticipate the arguments of the other groups and address them in their presentations as well. Encourage them to present their information clearly, assume others in the community do not have a background in climate science, and use visuals.

Students may tend to focus on one or two arguments that they think most strongly support their position. Remind them that they need to consider and include scientific information relating to all the concepts listed in their student book.

Process

Purpose

Students synthesize what they have learned in this chapter and appreciate the complex nature of climate science.

SHARE

Prior to the mock public meeting, have students share the written summary of their positions with other groups. This will give all groups a chance to adjust their presentations to address the concerns that are raised by the other groups.

Set up the classroom like an actual public meeting. That means there should be places for participants to sit, and a moderator (you?) to facilitate the meeting and make sure all have a chance to express their viewpoint. You may want to invite some outside guests to serve as other members of the Kivalina community and listen to the presentations. These other participants could ask questions and give feedback to the teams (how clear and convincing were their presentations? Were there any aspects of the science that they found confusing?. They could also participate in the vote and help make the community's decision about what it should do.

Structure the public meeting so that all viewpoints are heard and students are encouraged to listen carefully to each other's arguments and concerns. Once all of the groups have had a chance to present their initial arguments, let them know that they are then free to change their positions. In fact, if they do, that shows that they are really listening and considering what others have said. The students, posing as community members, will need to make a decision about which of the three courses to take. You may decide whether the decision will be made with a simple vote, or if you want the students to try harder to reach a consensus through further discussion and multiple votes.

Listening for Understanding

As you listen to the arguments presented by the students, listen to make sure they understand the many factors that affect climate both globally and regionally. As they discuss the science concepts, listen to make sure they use (and understand) the new vocabulary that was introduced in this unit.

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summary must include scientific information relating to all of the following concepts you studied in this chapter:

- The greenhouse effect and how CO_2 concentrations in the atmosphere can cause the climate to warm
- Other factors, such as the albedo effect, that affect how much heat is retained near Earth's surface
- Processes that contribute to or remove CO_2 from the atmosphere
- How human activities add to or subtract CO_2 from the atmosphere
- How positive and negative feedback loops can stabilize climate or accelerate change

Before the public meeting, share your written summary with your classmates, and read the summaries written by the groups with the other two viewpoints. Remember that your recommendations are being presented to your neighbors, who are not scientists. Convince them that you have a sophisticated understanding of this topic, but be sure to explain your information clearly. Think about what helps you understand a topic—use explanations that are precise and easy to understand, and use pictures and diagrams that will make the information clearer and emphasize your key points.

Consider Investigate **Process**

SHARE

You and your classmates will hold a public meeting, playing the role of members of the Kivalina community. Share your thinking about what the change in climate means for your community and what you should do. It's important for you to listen carefully to the groups that have a different viewpoint, so that you can come to a consensus about actions your community should take.

DISCUSS

Draw on the knowledge you've acquired in this chapter as you discuss these questions with your classmates. Your teacher may also ask you to record the answers in your notebook.

1. Think about how your personal ideas about the Kivalina situation were affected by the other ideas expressed at the public meeting. Describe something someone in another group said that you found convincing.
   a. Did your personal position initially differ from that assigned to your team? If so, how?
   b. Did you find that your position changed as you prepared your presentation?
   c. Did your position change after you listened to the arguments of the other groups?

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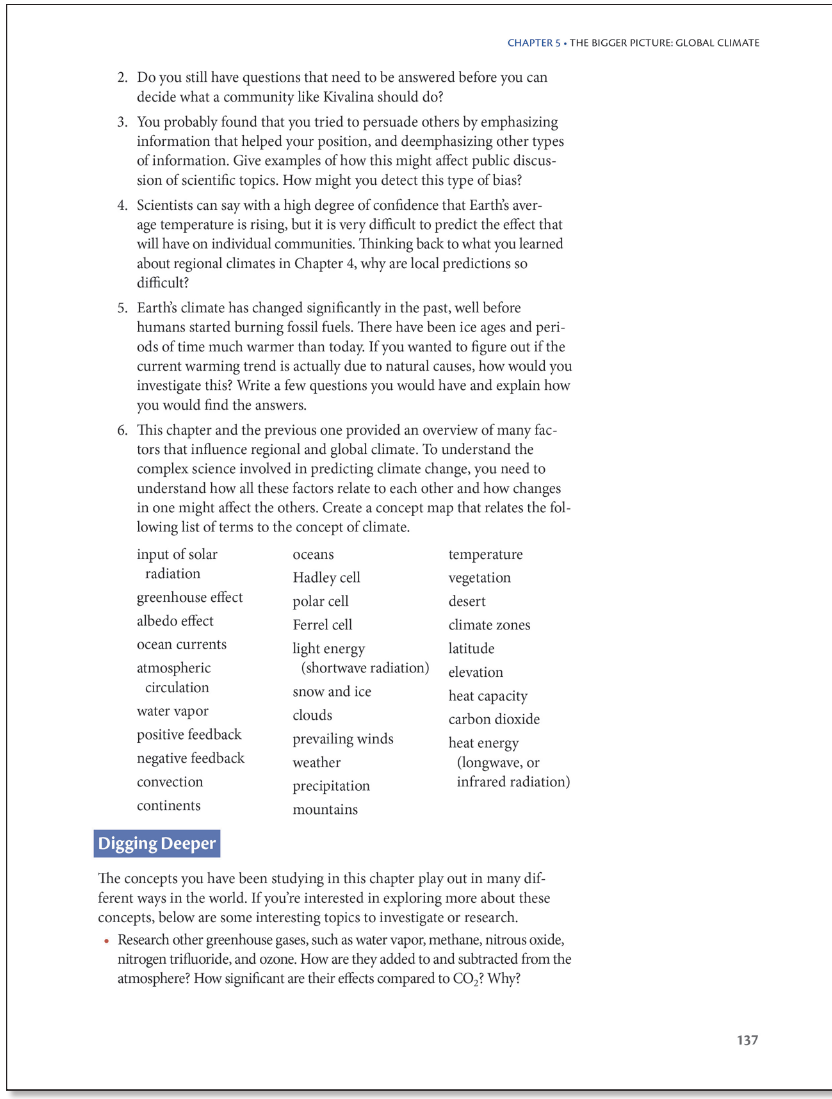
Background

Kivalina, Alaska

The Inupiat community of Kivalina has been struggling with the effects of global warming for several decades. The situation was already so difficult that by 1992 that people in the community voted to relocate. U.S. government reports in years since then have confirmed the need to move the village to a safer location. However, relocation has proved difficult and expensive—in fact, the cost has been estimated at $400 million, much more than the community can afford.

In 2008, in a high-profile case, Kivalina filed a lawsuit against a large group of energy companies, asserting that the emissions of CO_2 from these companies contributed to the global warming that threatens their community. They want the energy companies to pay to move Kivalina. After the lawsuit was rejected by lower courts, Kivalina in 2013 filed a petition to the U.S. Supreme Court to hear its case. Encourage students to research what has happened to the lawsuit and to the people of Kivalina.



CHAPTER 5 • THE BIGGER PICTURE: GLOBAL CLIMATE

2. Do you still have questions that need to be answered before you can decide what a community like Kivalina should do?
3. You probably found that you tried to persuade others by emphasizing information that helped your position, and deemphasizing other types of information. Give examples of how this might affect public discussion of scientific topics. How might you detect this type of bias?
4. Scientists can say with a high degree of confidence that Earth's average temperature is rising, but it is very difficult to predict the effect that will have on individual communities. Thinking back to what you learned about regional climates in Chapter 4, why are local predictions so difficult?
5. Earth's climate has changed significantly in the past, well before humans started burning fossil fuels. There have been ice ages and periods of time much warmer than today. If you wanted to figure out if the current warming trend is actually due to natural causes, how would you investigate this? Write a few questions you would have and explain how you would find the answers.
6. This chapter and the previous one provided an overview of many factors that influence regional and global climate. To understand the complex science involved in predicting climate change, you need to understand how all these factors relate to each other and how changes in one might affect the others. Create a concept map that relates the following list of terms to the concept of climate.

input of solar radiation	oceans	temperature
greenhouse effect	Hadley cell	vegetation
albedo effect	polar cell	desert
ocean currents	Ferrel cell	climate zones
atmospheric circulation	light energy (shortwave radiation)	latitude
water vapor	snow and ice	elevation
positive feedback	clouds	heat capacity
negative feedback	prevailing winds	carbon dioxide
convection	weather	heat energy (longwave, or infrared radiation)
continents	precipitation	
	mountains	

Digging Deeper

The concepts you have been studying in this chapter play out in many different ways in the world. If you're interested in exploring more about these concepts, below are some interesting topics to investigate or research.

- Research other greenhouse gases, such as water vapor, methane, nitrous oxide, nitrogen trifluoride, and ozone. How are they added to and subtracted from the atmosphere? How significant are their effects compared to CO_2? Why?

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DISCUSS

After students have completed their presentations, have them consider the following questions and discuss them as a class.

Possible Responses to the *Discuss* Questions

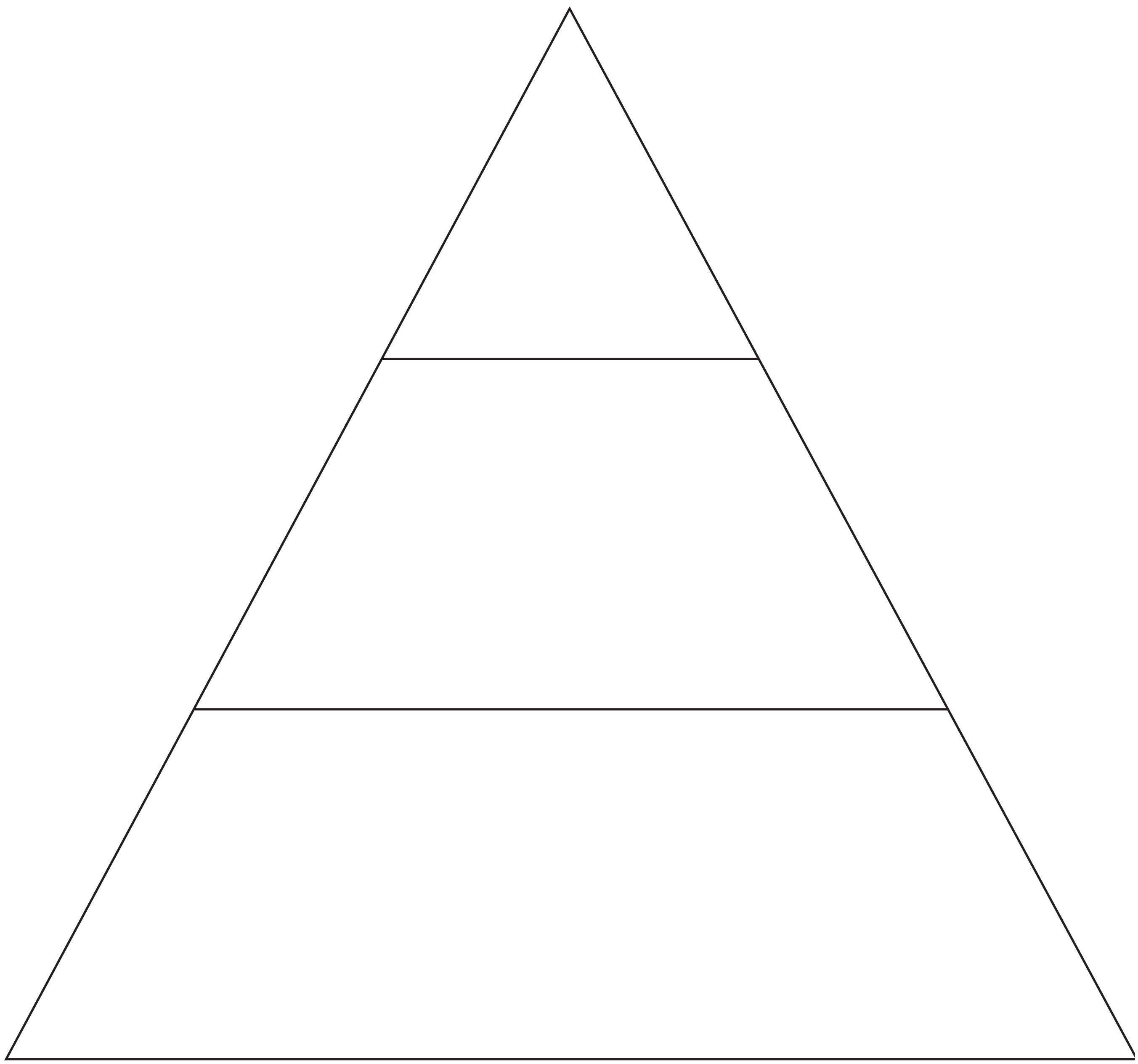
1. Think about how your personal ideas about the Kivalina situation were affected by the other ideas expressed at the public meeting. Describe something someone in another group said that you found convincing.
   a. Did your personal position initially differ from that assigned to your team? If so, how? *Answers will vary.*
   b. Did you find that your position changed as you prepared your presentation? *Answers will vary. Students may find that they personally took on the position that they were assigned, because they focused on evidence that supported their case.*
   c. Did your position change after you listened to the arguments of the other groups? *Answers will vary (in part by how carefully and critically they listened to the opposing teams' arguments).*
2. Do you still have questions that need to be answered before you can decide what a community like Kivalina should do? *If students have thought about this carefully, they are likely to still have many questions not answered in this chapter. For example, how do they know this is a long-term trend? Could there be other factors that will create a negative feedback loop and stabilize the climate? How do scientists know that the warming trend isn't caused by natural processes rather than by fossil-fuel combustion? How do they know the increasing amount of CO_2 in Earth's atmosphere doesn't come from another source? Could Kivalina's troubles be due to some other factor not related to global warming, such as a shift in ocean currents or prevailing winds? Are the energy companies really to blame or is everyone who uses the energy? Students may wonder about how data regarding global climate is collected; in other words, how do scientists know Earth is warming?*

NAME ____PERIOD__________________ DATE ____________________

LITERACY SUPPLEMENT 5.2

Science Fact Triangle for "The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops"

Use the top level of the triangle to record the *main idea* of the reading, the middle level to record *important facts* or *concepts* that helped you decide the main idea, and the bottom level for smaller *details* you would like to remember.



EDC EARTH SCIENCE SEMESTER 1

The first semester introduces students to Earth's systems and focuses on the hydrosphere and atmosphere. Students explore the sources of freshwater on the continents and the effects of currents in the world's oceans. They delve into the science of climate and climate change, exploring the factors that affect climate locally and globally and investigating the causes of climate change in Earth's past.

CHAPTER	SCIENCE CONCEPTS	LEARNING ACTIVITIES
INTRODUCING EARTH SCIENCE		
Chapter 1 Comparing Earth to Other Worlds	Introduction to Earth's systems; basic requirements for sustaining life	Students read an excerpt from a science fiction story about Mars colonists and analyze the resources necessary to sustain human populations on this neighboring planet.
UNIT 1: HYDROSPHERE: WATER IN EARTH'S SYSTEMS		
Chapter 2 Life's Blood: Seeking Water from Earth	Water cycle; surface water, groundwater, assessing and protecting water supplies	Students learn about droughts in Texas and Tennessee, and consider how access to plentiful and clean water is critical to human survival. They build their knowledge about how water is obtained by reviewing the water cycle and learning the science behind surface and groundwater supplies. After researching case studies from communities around the world, they get up close and personal, evaluating where their water comes from and whether their supply could be threatened in the future.
Chapter 3 Rivers of the Sea: Ocean Currents	Global patterns of ocean circulation; how wind and density differences drive ocean currents; global conveyor belt; El Niño	Students read a true story about Thor Heyerdahl, the explorer who set sail across the Pacific in the primitive raft Kon-Tiki to prove a theory. Drifting on an ocean current, he sought to show that people from South America could have migrated to Polynesia over 1,000 years ago without the benefit of developed seafaring vessels. Students gather knowledge about the science of ocean currents to decide whether his idea was crazy or had a chance of success.
UNIT 2: ATMOSPHERE AND CLIMATE		
Chapter 4 Local Connections: Regional Climate	Climate and weather; influence of latitude, atmospheric circulation, proximity to ocean, elevation, land features, and prevailing winds on regional climate	Students start their exploration of climate close to home, learning about the climate in their local area and comparing it to a chosen travel destination. Students learn how climate is measured and how it affects the flora and fauna of a landscape. They investigate key factors that cause climate to vary so much around the world.
Chapter 5 The Bigger Picture: Global Climate	Energy balance, albedo effect, greenhouse effect, carbon cycle, positive and negative feedback loops	Students read about a community in Alaska that is threatened by global warming and research the factors that influence global climate and can cause it to change. Based on what they've learned, they consider whether members of the Alaskan community should move or stay, and prepare recommendations to share at a public meeting.
Chapter 6 The Longest Experiment: Climate Change in Earth's History	Paleoclimatology, climate proxies, climate change in Earth's past, Milankovitch cycles, tectonic processes that influence climate, human impact on climate	Students explore two time periods in Earth's past when climate was very different from today—the warm Cretaceous and a glacial interval of the Pleistocene. Students study evidence—recorded in sediments, rocks, and ice—that climate has varied through Earth's history, and explore the factors that have contributed to these changes. They look at evidence that Earth's climate is changing now and how human activity and natural factors contribute to this change.
MID-YEAR CHALLENGE		
Chapter 7 Broadcast from the Future	Synthesis of concepts learned in the first part of the course	Students use the knowledge they have gained during the first semester of this course to make predictions about what Earth will be like in the year 2100. They communicate their predictions in a news broadcast from the future.

EDC EARTH SCIENCE SEMESTER 2

During the second semester of *EDC Earth Science*, students gain a deeper understanding of Earth's systems by exploring Earth's place in the universe and the workings of the geosphere. They study how solar systems form as part of the life cycle of stars and investigate how Earth's interior and surface are moving and changing. They examine evidence of tectonic plate movement as they investigate volcanic eruptions and earthquakes that have occurred in the western United States. They explore rock cycle processes and use clues in rocks to determine events that have happened in Earth's past. After gaining a greater appreciation of Earth's geosphere, students revisit the solid Earth from a human perspective. They explore how the geosphere provides critical natural resources, and how human's use of these resources has affected the balance of Earth's systems.

CHAPTER	SCIENCE CONCEPTS	LEARNING ACTIVITIES
UNIT 3: EARTH'S PLACE IN THE UNIVERSE		
Chapter 8 Stars, Planets, and Everything in Between: Solar System Origins	Solar system formation, Kepler's Laws, radioactive dating, life cycle of stars, spectroscopy	Students explore Earth's place in the universe by investigating how planets and solar systems form as part of the life cycles of stars. They gather evidence for the solar nebular theory from the observable patterns of motion in the solar system. They learn about methods for dating the age of Earth and other solar system objects. They investigate planets, asteroids, comets, and other solar system neighbors, and compare different models that account for the birth of the solar system and the life and death of stars. They learn about Kepler's Laws of Motion and investigate the geometry of movement of orbits. They conduct a mock trial to examine evidence for the solar nebular condensation theory, and examine line spectra used by astronomers to investigate the composition of objects located many light years from Earth.
Chapter 9 Journey to the Center of the Earth: Exploring Earth's Interior	Earth's interior structure and composition, internal sources of heat energy, seismic waves, introduction to plate tectonic theory, driving forces of plate movement	Students begin their exploration of the geosphere by looking down at their feet and wondering what lies below them. If they could dig through the floor, through the foundation of their building, through the soil and rocks, and keep going and going, what would they see? They explore Earth's internal structure, as well as the movements and changes that occur within the planet that have a profound effect on Earth's surface. Ultimately, students synthesize their understanding of Earth's interior by creating a "journey" into the earth, communicating scientific information about what they would encounter along the way.
UNIT 4: PLATE TECTONICS		
Chapter 10 On Shaky Ground: Earthquakes and Transform Boundaries	Transform-fault boundaries, earthquakes, physical and computer models, earthquake forecasting	Students read about the 1906 San Francisco earthquake and study the relationship of this event to the transform-fault boundary along the west coast of California. They use global-positioning-system (GPS) data to track plate motions, build a physical model to understand movements along the fault, and study computer models scientists use to forecast when and where earthquakes will occur.
Chapter 11 Sleeping Dragons? Subduction-Zone Volcanoes	Subduction zones, volcanoes and types of volcanic eruptions, technologies for volcano monitoring, data analyses	Students examine the relationship of the Cascade volcanoes in Washington, Oregon, and California to the subduction zone along the Northwest coast. They plot earthquake data to delineate a subduction zone and learn how scientists monitor changes beneath a volcano that may signal an imminent eruption. Ultimately, students apply information about the eruptive histories of the Cascade volcanoes, combined with current monitoring data, to assess the risk associated with living near volcanoes such as Mount Rainier.
Chapter 12 Clues on the Ocean Floor: Divergent Boundaries	Seafloor spreading, paleomagnetism, plate tectonics summary, landforms associated with plate boundaries	Students explore the process of seafloor spreading occurring along the Mid-Atlantic Ridge, looking for patterns in maps of earthquake distribution, seafloor topography, ocean crust age, and paleomagnetic data. They pull together what they've learned about plate tectonic processes that occur along divergent, convergent, and transform-plate boundaries.

UNIT 5: THE ROCK CYCLE		
Chapter 13 Mississippi Blues: Sedimentary Processes in a Delta	Erosion and deposition, deltaic processes, formation of sedimentary rock	Students investigate the ways in which river deltas build new land, reading about the plight of New Orleans in the aftermath of Hurricane Katrina. Students model the role the river played in forming the land in Louisiana and investigate why the land beneath New Orleans is sinking now. They use sediment core data to construct cross sections of the subsurface along levees that failed during Hurricane Katrina, and think about what can and should be done to keep this city from drowning in the future.
Chapter 14 A Solid Foundation: Building Earth's Crust	The nature of rocks and minerals, rock cycle, relative dating, Earth's history	Students read about James Hutton, known as the father of geology. They study samples of the rocks and minerals that make up the crust, and learn how to recognize clues that tell them true stories about Earth's history.
UNIT 6: EARTH RESOURCES		
Chapter 15 Hidden Treasures in Rocks: Mineral Resources	The geologic processes by which mineral ores are formed, mineral prospecting, mineral extraction and processing	Students explore the surprising extent to which they rely on Earth's crust for the materials in the objects around them. Putting themselves in the shoes of mineral prospectors, they gain expertise in the different ways that mineral ores become concentrated within Earth's crust. They analyze river-sediment samples to search for molybdenum ore and refine copper from samples of malachite. Ultimately, they devise their own business plans for developing a mineral resource.
Chapter 16 The Mystery of the Rub' al-Kahli: Energy Resources in Earth's Crust	Fossil fuel formation, petroleum resources and exploration technologies	Students read about the Rub' al-Kahli—a desolate desert landscape in Saudi Arabia that overlays one of the largest oil reservoirs in the world. Students investigate how oil reservoirs form naturally in Earth's crust, and how geologists go about finding this precious resource. They then use their new knowledge to figure out why there is so much more oil in some regions than there is in others.
FINAL CHALLENGE		
Chapter 17 A Different Earth	Synthesis of concepts learned in Earth Science 2	Students imagine a future when Earth's core has cooled completely. They use the knowledge they have gained about the geosphere to describe how this planet would be different.

requires students to synthesize their learning throughout the semester. The units within the two semesters are as follows:

EDC Earth Science Semester 1

Unit 1: Hydrosphere: Water in Earth's Systems
Unit 2: Atmosphere and Climate
Mid-Year Challenge

EDC Earth Science Semester 2

Unit 3: Earth's Place in the Universe
Unit 4: Plate Tectonics
Unit 5: The Rock Cycle
Unit 6: Earth Resources
Final Challenge

You will find more information regarding the content of this course at the beginning of each chapter in the teacher edition, along with information about the crosscutting concepts and scientific practices embedded in the chapter activities and readings.

NGSF ALIGNMENT

The following table shows the correlation between the concepts addressed in *EDC Earth Science* and *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012).

Correlation of *EDC Earth Science* with the *Next Generation Science Framework* Core Ideas High School (9–12)

	UNIT	CHAPTER
ESS1 EARTH'S PLACE IN THE UNIVERSE		
ESS1.A: THE UNIVERSE AND ITS STARS		
The star called the Sun is changing and will burn out over a life span of approximately 10 billion years.	3: Earth's Place in the Universe	8
The sun is just one of a myriad of stars in the Milky Way galaxy, and the Milky Way is just one of hundreds of billions of galaxies in the universe.	3: Earth's Place in the Universe	8
The study of stars' light spectra and brightnesses is used to identify compositional elements of stars, their movements, and their distances from Earth.	3: Earth's Place in the Universe	8
ESS1.B: THE EARTH AND THE SOLAR SYSTEM		
Kepler's Laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun.	3: Earth's Place in the Universe	8
Orbits may change due to the gravitational effects from, or collisions with, other bodies.	3: Earth's Place in the Universe	8
Gradual changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes.	2: Atmosphere and Climate	6
ESS1.C: THE HISTORY OF PLANET EARTH		
Radioactive-decay lifetimes and isotopic content in rocks provide a way of dating rock formations and thereby fixing the scale of geological time.	3: Earth's Place in the Universe 5: The Rock Cycle	8 14
The continents' rocks (some as old as 4 billion years or more) are much older than rocks on the ocean floor (less than 200 million years), where tectonic processes continually generate new rocks and remove old ones.	3: Earth's Place in the Universe 4: Plate Tectonics 5: The Rock Cycle	9 10–12 14
Although active geological processes, such as plate tectonics (link to ESS2.B) and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.	3: Earth's Place in the Universe 4: Plate Tectonics 5: The Rock Cycle	8. 9 10–12 13, 14
ESS2: EARTH'S SYSTEMS		
ESS2.A: EARTH MATERIALS AND SYSTEMS		
Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts.	1: Hydrosphere: Water in Earth's Systems 2: Atmosphere and Climate 4: Plate Tectonics	2, 3 4–6 10, 11
Evidence from deep probes and seismic waves, reconstructions of historical changes in the earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid but plastic mantle, and a solid surface crust.	3: Earth's Place in the Universe	9

Correlation of *EDC Earth Science* with the *Next Generation Science Framework* Core Ideas High School (9–12)

	UNIT	CHAPTER
The top part of the mantle, along with the crust, forms structures known as tectonic plates. Motions of the mantle and its plates are driven by convection (i.e., the flow of matter due to the energy transfer from the interior outward and the gravitational movement of denser materials toward the interior).	3: Earth's Place in the Universe 4: Plate Tectonics	9 10–12
The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities.	2: Atmosphere and Climate	4–6
These changes can occur on a variety of time scales from sudden (e.g., volcanic dust clouds) to intermediate (ice ages) to very-long-term tectonic cycles.	2: Atmosphere and Climate	4–6
ESS2.B: PLATE TECTONICS AND LARGE-SCALE SYSTEM INTERACTIONS		
The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle. This energy moves through and out of the planet's interior, primarily by mantle convection.	3: Earth's Place in the Universe 4: Plate Tectonics	9 10
Plate tectonics can be viewed as the surface expression of mantle convection.	3: Earth's Place in the Universe 4: Plate Tectonics	9 10–12
ESS2.C: THE ROLES OF WATER IN EARTH'S SURFACE PROCESSES		
The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics.	1: Hydrosphere: Water in Earth's Systems 4: Plate Tectonics	2, 3 11
These properties include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; and lower the viscosities and melting points of rocks.	1: Hydrosphere: Water in Earth's Systems 2: Atmosphere and Climate 4: Plate Tectonics 5: The Rock Cycle 6: Earth Resources	2, 3 4–6 11 13, 14 15
ESS2.D: WEATHER AND CLIMATE		
Global climate is a dynamic balance on many different time scales among energy from the sun falling on Earth; the energy's reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems; and the energy's re-radiation into space.	2: Atmosphere and Climate	4–6
Climate change can occur if any part of Earth's systems is altered. Geological evidence indicates that past climate changes were either sudden changes caused by alterations in the atmosphere; longer term changes (e.g., ice ages) due to variations in solar output, Earth's orbit, or the tilt of its axis; or even more gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen.	2: Atmosphere and Climate	4–6
The time scales of these changes varied from a few to millions of years. Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.	2: Atmosphere and Climate	4–6
Global climate models incorporate scientists' best knowledge of physical and chemical processes and of the interactions of relevant systems. They are tested by their ability to fit past climate variations.	2: Atmosphere and Climate	6
Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise.	2: Atmosphere and Climate	6
The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and the biosphere. Hence the outcomes depend on human behaviors as well as on natural factors that involve complex feedbacks among Earth's systems.	2: Atmosphere and Climate	6
ESS2.E: BIOGEOLOGY		
The many dynamic and delicate feedbacks between the biosphere and other earth systems cause a continual coevolution of Earth's surface and the life that exists on it.	2: Atmosphere and Climate 3: Earth's Place in the Universe	4, 6 8

Correlation of *EDC Earth Science* with the *Next Generation Science Framework* Core Ideas High School (9–12)

	UNIT	CHAPTER
ESS3: EARTH AND HUMAN ACTIVITY		
ESS3.A: NATURAL RESOURCES		
Resource availability has guided the development of human society. All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks, as well as benefits.	1: Hydrosphere: Water in Earth's Systems 6: Earth Resources	2 15, 16
New technology and regulation can change the balance of these factors.	1: Hydrosphere: Water in Earth's Systems 6: Earth Resources	2 15, 16
ESS3.B: NATURAL HAZARDS		
Natural hazards and other geological events have shaped the course of human history by destroying buildings and cities, eroding land, changing the course of rivers, and reducing the amount of arable land.	4: Plate Tectonics 5: The Rock Cycle	10, 11 12, 13
These events have significantly altered the sizes of human populations and have driven human migrations.	1: Hydrosphere: Water in Earth's Systems 4: Plate Tectonics 5: The Rock Cycle	2 10, 11 13
Natural hazards can be local, regional, or global in origin, and their risks increase as populations grow. Human activities can contribute to the frequency and intensity of some natural hazards.	1: Hydrosphere: Water in Earth's Systems 4: Plate Tectonics 5: The Rock Cycle	2 10–12 13
ESS3.C: HUMAN IMPACTS ON EARTH SYSTEMS		
The sustainability of human societies and of the biodiversity that supports them require responsible management of natural resources not only to reduce existing adverse impacts but also to get things right in the first place.	1: Hydrosphere: Water in Earth's Systems 6: Earth Resources	2 15, 16
Scientists and engineers can make major contributions—for example, by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.	1: Hydrosphere: Water in Earth's Systems 6: Earth Resources	2 15, 16
When the source of a problem is understood and international agreement can be reached, it has been possible to regulate activities to reverse or avoid some global impacts (e.g., acid rain, the ozone hole).	2: Atmosphere and Climate 6: Earth Resources	6 16
ESS3.D: GLOBAL CLIMATE CHANGE		
Because global climate changes usually happen too slowly for individuals to recognize them directly, scientific and engineering research—much of it based on studying and modeling past climate patterns—is essential.	2: Atmosphere and Climate	5, 6
The current situation is novel, not only because the magnitudes of humans' impacts are significant on a global scale but also because humans' abilities to model, predict, and manage future impacts are greater than ever before.	2: Atmosphere and Climate	5, 6
Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities, as well as to changes in human activities. Thus science and engineering will be essential both to understanding the possible impacts of global climate change and to informing decisions about how to slow its rate and consequences—for humanity as well as for the rest of the planet.	2: Atmosphere and Climate	5, 6