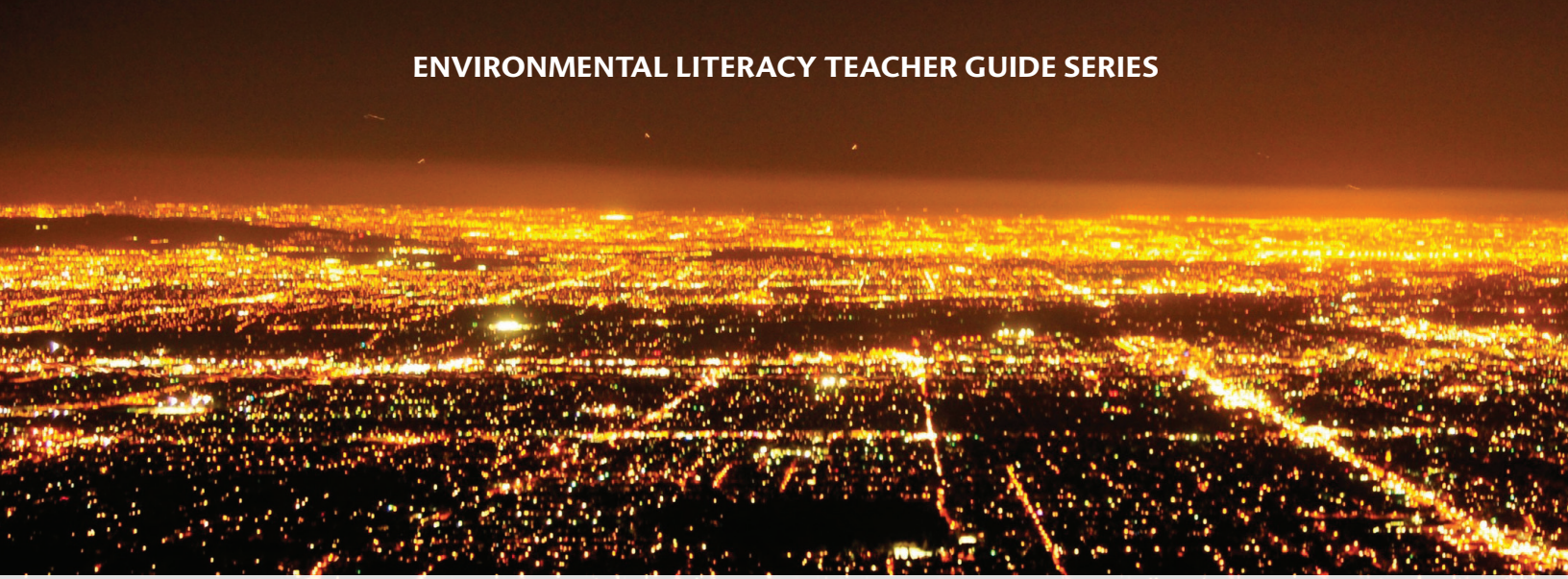
ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES



Changing Climate

A Guide for Teaching Cimate Change in Grades 3 to 8

NATIONAL GEOGRAPHIC
education

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Project Managers for the Environmental Literacy Teacher Guide Series:

Julie Brown
Education Specialist
National Geographic Society

Lindsey Mohan
Manager, Climate Education
National Geographic Society

Kathleen Schwille
Director of Program Development
National Geographic Society

Contributors

Authors:
Tania T. Hinojosa, Jenny D. Ingber, Nicole D. LaDue, Jose Marcos-Iga, Lindsey Mohan, and Tara G. Treiber

Reviewers:
Catie Boarts, LuAnn Dahlman, Kristin M. Dell, Jenny D. Ingber, and Tara G. Treiber

Editors:
Kate Matracia and Chelsea M. Zillmer

Design:
Cindy Olson

Video Editors:
Rachel Dwiggins and Natalie Hays Stewart

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For more information contact

Heal the Bay
1444 9th Street
Santa Monica, CA 90401
www.healthebay.org

National Geographic Education Programs
1145 17th Street NW
Washington, DC 20036
www.natgeoed.org

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California Education and the Environment Initiative

California has always been a leader in environmental education and conservation, including the existence of environmental content in its academic standards.

To increase California's impact on environmental education, Assembly Bill 1548 was passed into law in 2003 mandating the creation of a K–12 curriculum charged with incorporating more environmental education into the state's required academic content standards in Science and History/Social Science. The bipartisan law was supported by various state and nonprofit groups, and marked the beginning of the landmark Education and the Environment Initiative (EEI). The law helped solidify California's leadership role in improving national and international environmental education.

EEI Principles and Model Curriculum

With an emphasis on students' relationship with the environment, EEI aims to increase environmental literacy in a format familiar to California teachers. Critical environmental issues, such as climate change, freshwater, ocean, energy, and other topics, are addressed in the law.

"This nation-leading initiative will educate our next generation of workers in environmental preservation and protection and will help catapult California's growing green economy."

Former Governor Schwarzenegger

ENVIRONMENTAL PRINCIPLES AND CONCEPTS

1. People depend on natural systems.
2. People influence natural systems.
3. Natural systems change in ways that benefit people and they can influence.
4. There are no permanent or impermeable boundaries that prevent matter from flowing between systems.
5. Decisions affecting resources and natural systems are complex and involve many factors.

Creation of this unprecedented curriculum began in 2004 with the development of the California Environmental Principles and Concepts (EP&C), which clearly highlight the relationship between humans and the environment. In addition to the Environmental Principles and Concepts, EEI also developed a Model Curriculum that was comprised of weeklong units for K–12 teachers to use in their own classrooms. Development of the Model Curriculum began in 2005, with a focus on aligning the unit content to California's academic standards. From 2006–2009, the California EPA worked with partners, such as the California Department of Education, to create a curriculum that would be comprehensive and innovative, while continuing to teach academic content standards for Science and History/Social Science. More than 200 teachers and 600 students in 19 school districts across the state piloted the Model Curriculum units in 2007–2008 in order to test that the materials would be easily implemented in the classroom. Even more teachers and content experts independently reviewed the materials, making certain that the units fit with established classroom and assessment practices and would not burden teachers who would be using the curriculum. At the end, EEI developed 85 curriculum units spanning grades K–12, which were approved by the State Board of Education in Spring 2010.

The EEI Model Curriculum is poised to reshape how the environment is taught and presented to California's students. The California/Environmental Protection Agency (Cal/EPA), in partnership with the Department of Education, will be reaching out to inform teachers about how the curriculum can be used independently from, in conjunction with, or integrated into current instructional materials. The EEI curriculum will be made available electronically to school districts and teachers, free of charge, which will greatly increase the number of teachers who can easily access the materials. Find out more about the EP&C's and the EEI Model Curriculum at http://www.calepa.ca.gov/education/eei/.

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.a-e	Structures for Survival in a Healthy Ecosystem Living Things in Changing Environments
Grade 4	4.2.a-c 4.3.a-b	Plants: The Ultimate Energy Resource The Flow of Energy Through Ecosystems Life and Death with Decomposers
Grade 5		
Grade 6	6.5.a-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.a 7.3.e	Shaping Natural Systems Through Evolution Responding to Environmental Change
Grade 8		

Each teacher guide chapter includes a table that aligns the content in the chapter to California state science and social studies academic standards, and to the EEI Model Curriculum.

Connecting EEI to the Teacher Guide Series

The hope of the EEI is to provide cutting-edge environmental content to students, while supporting them in achieving academic content standards. Given the environmental topics addressed by the units, professional development is needed so teachers feel confident and effective in delivering this content in their classrooms. Whether using the EEI Model Curriculum or other educational materials about the environment, teachers will need additional preparation to feel comfortable with teaching about the latest environmental issues.

The Environmental Literacy Teacher Guide Series responds to this need, providing both content background for teachers on these environmental issues, as well as providing information about concepts that likely will be challenging for students to learn. The Environmental Literacy Teacher Guide Series includes Climate Change, Ocean, Freshwater, and Energy guides. Each teacher guide is intended to prepare upper elementary and middle school teachers for instruction in these content areas.

The content and educational components of the teacher guides are aligned to both California Standards, and the units in the EEI Model Curriculum, allowing teachers to use specific chapters as resource when teaching those standards and units. While the goal of the teacher guide is not to prepare teachers for using a specific EEI unit, it is hoped that the information provided by the guide helps teachers feel more confident and prepared to teach about these topics in the classroom, and to anticipate what their students will know and struggle with as they learn the EEI units, or similar environmental curriculum.

Why Is Climate Change Education Important?

Is our climate changing? Is there global warming? Haven't there always been cycles of warming and cooling on Earth? What about the Greenhouse Effect? Is it a good thing or bad thing? Can one individual do anything to make a difference on this issue?

Over the last few years, we have heard a great deal of discussion about climate change. Most of us do little more than pay attention to what the day's weather will be and if we need to take a jacket or umbrella as we head out the door. Wading through an abundance of conflicting information can seem daunting. Who do we believe? How can we begin to be scientifically literate if we are not clear about how scientific work is conducted? The good news is that because of the scientific process itself, ideas are tested repeatedly before they are published in scientific journals. Before work can be published, it must undergo "peer review." It is read and scrutinized by a panel of scientists in the same field, and they determine if the work has been adequately tested and if the procedures followed during the test were appropriate. Often professional organizations also serve as reviewers of scientific work.

While climate change may not cross our minds everyday, our lives are inextricably intertwined with local and global changes in climate. For example, are we changing our eating patterns because food prices are escalating due to droughts or floods or fires? Do our water sources still supply sufficient water to meet our needs? Some people may already be asking the question: Can we continue to live where we currently live or has our livelihood already been impacted by changes? It seems incredible that so many aspects of our daily lives are actually impacted by the climate, but as the climate continues to change, more and more of these questions will come up for everyday citizens.

In 1989, a Presidential Initiative cited the need to research the changes in the global environment. In 1990, Congress passed the Global Change Research Act, which teamed the talents and resources of 13 agencies (e.g., State Department, NASA, NSF, Smithsonian, Department of Interior, and so on) to coordinate endowments of research and educational programs to better understand this issue and its contributing factors. Increasing temperatures have an impact on coastal, riverside, and agricultural communities. Fruit harvests are seriously impacted not only by drought, fire, and flooding, but also by the lack of adequate cool temperatures to set the fruit. Growing seasons are altered as temperatures change. Many living things are relocating or facing extinction due to unlivable conditions caused by increasingly severe and frequent weather events.

It seems incredible that so many aspects of our daily lives are actually impacted by the climate.

Americans are not alone in this realization. Because climate change is a global issue, in 1997, representatives from around the world met in Kyoto, Japan, to address the challenges created by the emissions of **greenhouse gases.** There were discussions and commitments to lessening these emissions. In 2009, nations around the world came together again in Copenhagen, Denmark, to discuss these issues. At Kyoto and Copenhagen alike, many nations made commitments to reduce their emissions of greenhouse gases and focus on solving climate change.

As governments commit to addressing the issues on an international level, many individuals are also becoming aware of what they can do on a personal

level. Citizens are looking at their activities and how they can decrease their reliance on products that emit greenhouse gases, thus, reducing their "carbon footprint." Many people are speaking up and lobbying their school or business cafeterias and restaurants to reduce wasteful use of products. Some people are using their power as consumers of "green products," which use less energy to produce or operate, and are, thus, influencing manufacturers who want to stay competitive. Others are carpooling or using alternatives to single-driver transportation.

In 2006, the governor of California signed into law the Global Warming Solutions Act (AB 32), which focused on reduction of greenhouse gases. This law was intended to bring California's greenhouse gas emissions into compliance with the Kyoto Protocol by the year 2020. This means bringing California's greenhouse gas emissions down to 1990 levels or lower. But what does this mean for California citizens or for students in California?

Educating youth about climate change and climate solutions will be necessary if future generations are going to help solve the problem. Yet, few resources are provided to educators to accomplish this goal. Many teachers, and many states and local agencies, have recognized the need for resources on environmental topics. Teachers have struggled to develop units on their own to help address the issues, while states have looked to rectify it through legislation. With the passage of Assembly Bill 1548 of 2003, commonly referred to as the Education and the Environment Initiative (EEI), the state of California is attempting to bridge the gap between real-world and theoretical learning connecting the concepts students are learning to their environment. This initiative calls for mastery of standards and curricula on environmental topics, through the use of EEI curriculum or comparable curriculum on environmental topics. California is leading the charge against climate change and provides an excellent example of a state that has political leaders, innovative companies, and scientists working tirelessly on this issue. Furthermore, numerous community, city, and state initiatives and regulations provide excellent examples of how California citizens have used their voices—their voter and consumer power—to bring about changes to combat climate change. Students will be the consumers and decision-makers of tomorrow (in many cases they already are).

This guide was developed to support teachers in teaching topics with real-world context and provide them with the background to feel competent and comfortable when teaching about climate change. It provides a solid introduction to climate change in an accessible and reader-friendly manner. In addition to general information about climate change, the guide includes numerous education features, such as teaching tips and student thinking, that help to connect the content to classroom practice.

The book describes our current understanding of causes and consequences of climate change. Chapter 1 addresses the natural Greenhouse Effect on Earth, and the underlying causes of climate change. Chapter 2 takes a closer look at the carbon cycle and human activity that influences how carbon moves through natural systems. Chapter 3 looks at the human activities that use fossil fuels that are responsible for present-day climate change, examining issues related to energy use across time and how people meet their energy needs today. Chapter 4 provides more information about how scientists study climate change using proxy data from tree rings, ice cores, and other sources, while Chapter 5 discusses how scientists use this data to produce models of climate change. Chapter 5 includes an in-depth look at potential consequences of climate change. Finally, Chapter 6 addresses what is being done with respect to this issue, outlining some of the international and federal solutions being explored, as well as new ideas that could solve both our energy and climate problems. Solving the climate change problem is not a passive act, however, so Chapter 6 also provides ideas for actions that you and your students can take to reduce the impacts of climate change for generations to come.

Students will be the consumers and decision-makers of tomorrow.

With a greater sense of confidence in the subject matter, you can help lead your students through the content and choices that confront all of us. Why is learning about climate change important? What are actions we might take to mitigate or slow down the process? How can we lessen our carbon footprint as individuals, and in the organizations we belong to? With newfound understanding, you can teach climate change to your students, helping to create future generations who are climate literate, and who know how critical this issue is to preserving the planet we depend upon.

Teacher Guide Tour

Environmental Content

Environmental science includes a wealth of content that teachers may not learn as part of their professional preparation. Content pages provide teachers with an opportunity to learn this content alongside information about how students think about these topics. The content pages also reconsider fundamental science concepts in the context of environmental issues. Interesting and new concepts are in bold and defined in the accompanying glossary.

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.2 3.3.3 3.4.1-2 3.5.1-3	The Geography of Where We Live California's Economy—Natural Choices
Grade 4	4.1.3-5 4.4.6 4.5.3	Reflections of Where We Live
Grade 5	5.7.3	
Grade 6	6.6.a 6.6.b	Energy: It's Not All the Same to You! Energy and Material Resources: Renewable or Not?
Grade 7		
Grade 8	8.3.6 8.12.5	Industrialization, Urbanization, & Conservation

et al. 2010). Why is the alarmed and concerned 39 percent of the population not acting on their concerns? How can we bridge the gap between concern and action? Is education the answer?

A similar report titled Climate Change in the American Mind found that, even during the economic downturn, 90 percent of Americans think the United States should act to reduce climate change, even when there is a financial cost involved (Leiserowitz et al. 2010). Furthermore, more than 73 percent believe that climate change will harm Americans within the next 50 years, and 47 percent believe the harm is already being done or will be, within the next 10 years. Still, only a few alarmed Americans (8 percent) have actually contacted their elected officials about the issue within the last year.

Why are values not aligning with action? According to a report from the American Psychological Association (APA 2010), there are many emotional barriers that stand in the way of actions that would help solve the problem. Climate change is about large-scale systems over long periods, with uncertain outcomes. Research shows that while scientists generally are more concerned with long-term global

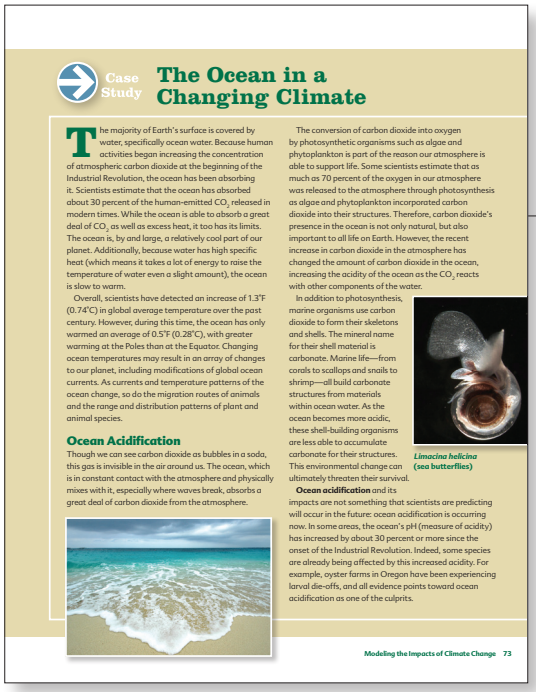
CHAPTER OVERVIEW

Taking action against climate change may seem daunting to some citizens, especially our students. Given a better understanding of climate change, students may develop a sense of empowerment and belief that even the smallest of actions can aggregate to have large-scale change.

This chapter discusses four types of solutions necessary to take action against climate change. Mitigation is one solution that focuses on reducing the causes of climate change. For example, regulating carbon dioxide emissions from vehicles is one mitigation strategy. Mitigation strategies are made possible through a second type of solution—innovation. With new innovative technologies, we can change the way we consume fossils fuels and the way we alter our landscape. New innovations can be factored into mitigation plans. Action on the part of people is a third solution that influences both mitigation and innovation. When people—as voters and consumers—place pressure on business and political leaders, those leaders and business owners will be more likely to listen to the needs of people in order to stay in office or stay in business. A last solution to climate change is to prepare for the changes already underway. Our communities are already faced with changes, and we will need adaptation strategies in order to cope with them.

Standards Table

Chapters are aligned to California state science and social studies standards, as well as aligned to the Education and Environment Initiative (EEI) model curriculum units.



Case Study

The Ocean in a Changing Climate

The majority of Earth's surface is covered by water, specifically ocean water. Because human activities began increasing the concentration of atmospheric carbon dioxide at the beginning of the Industrial Revolution, the ocean has been absorbing it. Scientists estimate that the ocean has absorbed about 30 percent of the human-emitted CO_2 released in modern times. While the ocean is able to absorb a great deal of CO_2 as well as excess heat, it too has its limits. The ocean is, by and large, a relatively cool part of our planet. Additionally, because water has high specific heat (which means it takes a lot of energy to raise the temperature of water even a slight amount), the ocean is slow to warm.

Overall, scientists have detected an increase of 1.3°F (0.74°C) in global average temperature over the past century. However, during this time, the ocean has only warmed an average of 0.5°F (0.28°C), with greater warming at the Poles than at the Equator. Changing ocean temperatures may result in an array of changes to our planet, including modifications of global ocean currents. As currents and temperature patterns of the ocean change, so do the migration routes of animals and the range and distribution patterns of plant and animal species.

Ocean Acidification

Though we can see carbon dioxide as bubbles in a soda, this gas is invisible in the air around us. The ocean, which is in constant contact with the atmosphere and physically mixes with it, especially where waves break, absorbs a great deal of carbon dioxide from the atmosphere.

The conversion of carbon dioxide into oxygen by photosynthetic organisms such as algae and phytoplankton is part of the reason our atmosphere is able to support life. Some scientists estimate that as much as 70 percent of the oxygen in our atmosphere was released to the atmosphere through photosynthesis as algae and phytoplankton incorporated carbon dioxide into their structures. Therefore, carbon dioxide's presence in the ocean is not only natural, but also important to all life on Earth. However, the recent increase in carbon dioxide in the atmosphere has changed the amount of carbon dioxide in the ocean, increasing the acidity of the ocean as the CO_2 reacts with other components of the water.

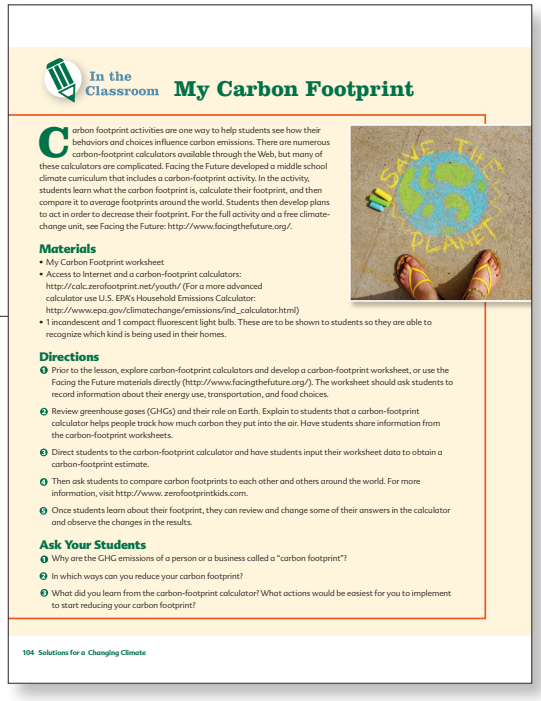
In addition to photosynthesis, marine organisms use carbon dioxide to form their skeletons and shells. The mineral name for their shell material is carbonate. Marine life—from corals to scallops and snails to shrimp—all build carbonate structures from materials within ocean water. As the ocean becomes more acidic, these shell-building organisms are less able to accumulate carbonate for their structures. This environmental change can ultimately threaten their survival.

Limacina helicina (sea butterflies)

Ocean acidification and its impacts are not something that scientists are predicting will occur in the future: ocean acidification is occurring now. In some areas, the ocean's pH (measure of acidity) has increased by about 30 percent or more since the onset of the Industrial Revolution. Indeed, some species are already being affected by this increased acidity. For example, oyster farms in Oregon have been experiencing larval die-offs, and all evidence points toward ocean acidification as one of the culprits.

Case Study

Case Studies offer an in-depth look at how concepts play out in particular locations or situations. Case studies provide real-life examples of how issues affect both natural and human communities today.



In the Classroom

My Carbon Footprint

Carbon footprint activities are one way to help students see how their behaviors and choices influence carbon emissions. There are numerous carbon-footprint calculators available through the Web, but many of these calculators are complicated. Facing the Future developed a middle school climate curriculum that includes a carbon-footprint activity. In the activity, students learn what the carbon footprint is, calculate their footprint, and then compare it to average footprints around the world. Students then develop plans to act in order to decrease their footprint. For the full activity and a free climate-change unit, see Facing the Future: http://www.facingthefuture.org/.

Materials

- My Carbon Footprint worksheet
- Access to Internet and a carbon-footprint calculators: http://calc.zerofootprint.net/youth/ (For a more advanced calculator use U.S. EPA's Household Emissions Calculator: http://www.epa.gov/climatechange/emissions/ind_calculator.html)
- 1 incandescent and 1 compact fluorescent light bulb. These are to be shown to students so they are able to recognize which kind is being used in their homes.

Directions

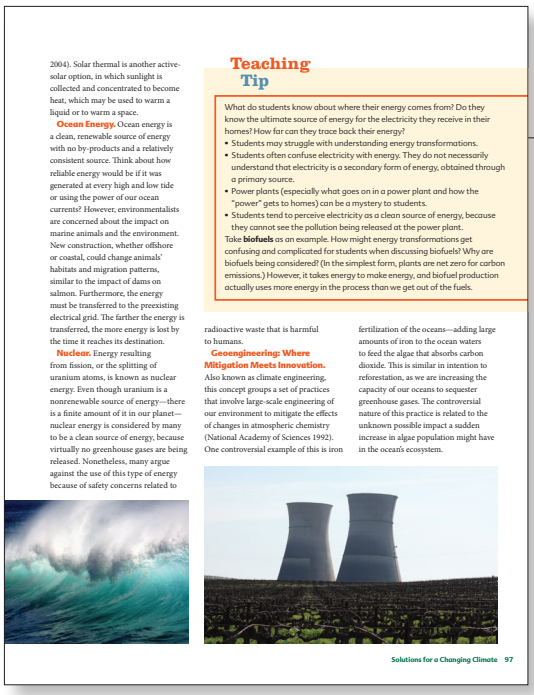
1. Prior to the lesson, explore carbon-footprint calculators and develop a carbon-footprint worksheet, or use the Facing the Future materials directly (http://www.facingthefuture.org/). The worksheet should ask students to record information about their energy use, transportation, and food choices.
2. Review greenhouse gases (GHGs) and their role on Earth. Explain to students that a carbon-footprint calculator helps people track how much carbon they put into the air. Have students share information from the carbon-footprint worksheets.
3. Direct students to the carbon-footprint calculator and have students input their worksheet data to obtain a carbon-footprint estimate.
4. Then ask students to compare carbon footprints to each other and others around the world. For more information, visit http://www. zerofootprintkids.com.
5. Once students learn about their footprint, they can review and change some of their answers in the calculator and observe the changes in the results.

Ask Your Students

1. Why are the GHG emissions of a person or a business called a "carbon footprint"?
2. In which ways can you reduce your carbon footprint?
3. What did you learn from the carbon-footprint calculator? What actions would be easiest for you to implement to start reducing your carbon footprint?

In the Classroom

In the Classroom features iconic or helpful classroom activities, as well as ideas for teaching topics. Details are provided to use the activity in the classroom, including materials lists and directions, as well as interesting discussion questions to ask your students. When possible, additional online resources are connected to the classroom activities.



2004). Solar thermal is another active-solar option, in which sunlight is collected and concentrated to become heat, which may be used to warm a liquid or to warm a space.

Ocean Energy. Ocean energy is a clean, renewable source of energy with no by-products and a relatively consistent source. Think about how reliable energy would be if it was generated at every high and low tide or using the power of our ocean currents? However, environmentalists are concerned about the impact on marine animals and the environment. New construction, whether offshore or coastal, could change animals' habitats and migration patterns, similar to the impact of dams on salmon. Furthermore, the energy must be transferred to the preexisting electrical grid. The farther the energy is transferred, the more energy is lost by the time it reaches its destination.

Nuclear. Energy resulting from fission, or the splitting of uranium atoms, is known as nuclear energy. Even though uranium is a nonrenewable source of energy—there is a finite amount of it in our planet—nuclear energy is considered by many to be a clean source of energy, because virtually no greenhouse gases are being released. Nonetheless, many argue against the use of this type of energy because of safety concerns related to radioactive waste that is harmful to humans.

Teaching Tip

What do students know about where their energy comes from? Do they know the ultimate source of energy for the electricity they receive in their homes? How far can they trace back their energy?

- Students may struggle with understanding energy transformations.
- Students often confuse electricity with energy. They do not necessarily understand that electricity is a secondary form of energy, obtained through a primary source.
- Power plants (especially what goes on in a power plant and how the "power" gets to homes) can be a mystery to students.
- Students tend to perceive electricity as a clean source of energy, because they cannot see the pollution being released at the power plant.

Take **biofuels** as an example. How might energy transformations get confusing and complicated for students when discussing biofuels? Why are biofuels being considered? (In the simplest form, plants are net zero for carbon emissions.) However, it takes energy to make energy, and biofuel production actually uses more energy in the process than we get out of the fuels.

Geoengineering: Where Mitigation Meets Innovation. Also known as climate engineering, this concept groups a set of practices that involve large-scale engineering of our environment to mitigate the effects of changes in atmospheric chemistry (National Academy of Sciences 1992). One controversial example of this is iron fertilization of the oceans—adding large amounts of iron to the ocean waters to feed the algae that absorbs carbon dioxide. This is similar in intention to reforestation, as we are increasing the capacity of our oceans to sequester greenhouse gases. The controversial nature of this practice is related to the unknown possible impact a sudden increase in algae population might have in the ocean's ecosystem.

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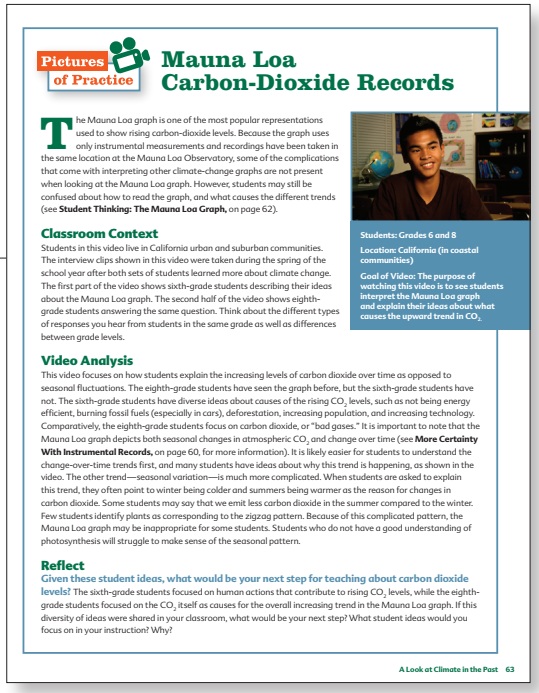
Teaching Tip

Throughout the content pages, **Teaching Tips** connect the content to classroom practice. Teaching Tips suggest practical activities and resources to consider when teaching about a particular topic. When available, Teaching Tips direct teachers to additional online resources.



Pictures of Practice

Mauna Loa Carbon-Dioxide Records

The Mauna Loa graph is one of the most popular representations used to show rising carbon-dioxide levels. Because the graph uses only instrumental measurements and recordings have been taken in the same location at the Mauna Loa Observatory, some of the complications that come with interpreting other climate-change graphs are not present when looking at the Mauna Loa graph. However, students may still be confused about how to read the graph, and what causes the different trends (see **Student Thinking: The Mauna Loa Graph,** on page 62).

Students: Grades 6 and 8

Location: California (in coastal communities)

Goal of Video: The purpose of watching this video is to see students interpret the Mauna Loa graph and explain their ideas about what causes the upward trend in CO_2

Classroom Context

Students in this video live in California urban and suburban communities. The interview clips shown in this video were taken during the spring of the school year after both sets of students learned more about climate change. The first part of the video shows sixth-grade students describing their ideas about the Mauna Loa graph. The second half of the video shows eighth-grade students answering the same question. Think about the different types of responses you hear from students in the same grade as well as differences between grade levels.

Video Analysis

This video focuses on how students explain the increasing levels of carbon dioxide over time as opposed to seasonal fluctuations. The eighth-grade students have seen the graph before, but the sixth-grade students have not. The sixth-grade students have diverse ideas about causes of the rising CO_2 levels, such as not being energy efficient, burning fossil fuels (especially in cars), deforestation, increasing population, and increasing technology. Comparatively, the eighth-grade students focus on carbon dioxide, or "bad gases." It is important to note that the Mauna Loa graph depicts both seasonal changes in atmospheric CO_2 and change over time (see **More Certainty With Instrumental Records,** on page 60, for more information). It is likely easier for students to understand the change-over-time trends first, and many students have ideas about why this trend is happening, as shown in the video. The other trend—seasonal variation—is much more complicated. When students are asked to explain this trend, they often point to winter being colder and summers being warmer as the reason for changes in carbon dioxide. Some students may say that we emit less carbon dioxide in the summer compared to the winter. Few students identify plants as corresponding to the zigzag pattern. Because of this complicated pattern, the Mauna Loa graph may be inappropriate for some students. Students who do not have a good understanding of photosynthesis will struggle to make sense of the seasonal pattern.

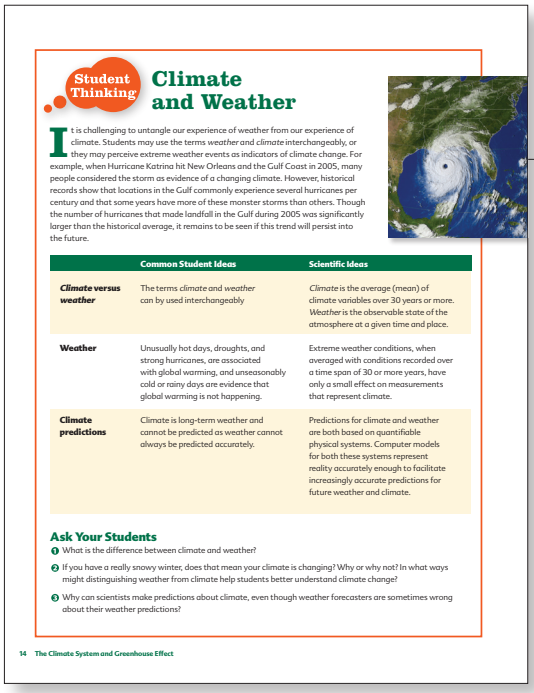
Reflect

Given these student ideas, what would be your next step for teaching about carbon dioxide levels? The sixth-grade students focused on human actions that contribute to rising CO_2 levels, while the eighth-grade students focused on the CO_2 itself as causes for the overall increasing trend in the Mauna Loa graph. If this diversity of ideas were shared in your classroom, what would be your next step? What student ideas would you focus on in your instruction? Why?

A Look at Climate in the Past 63

Pictures of Practice

Classroom video is a valuable resource for reflecting on practice. **Pictures of Practice** are videos, about two to five minutes in length, focusing on student ideas. The purpose of these videos is to capture everyday classroom life and to provide real-life examples of how students learn and think about these topics. The focus of the videos is on student participation and ideas, as opposed to the teacher and instructional style. Reading the video activity prior to watching the video will help prepare you to get the most out of the videos.



Student Thinking

Climate and Weather

It is challenging to untangle our experience of weather from our experience of climate. Students may use the terms *weather* and *climate* interchangeably, or they may perceive extreme weather events as indicators of climate change. For example, when Hurricane Katrina hit New Orleans and the Gulf Coast in 2005, many people considered the storm as evidence of a changing climate. However, historical records show that locations in the Gulf commonly experience several hurricanes per century and that some years have more of these monster storms than others. Though the number of hurricanes that made landfall in the Gulf during 2005 was significantly larger than the historical average, it remains to be seen if this trend will persist into the future.

	Common Student Ideas	Scientific Ideas
Climate* versus *weather	The terms *climate* and *weather* can by used interchangeably	*Climate* is the average (mean) of climate variables over 30 years or more. *Weather* is the observable state of the atmosphere at a given time and place.
Weather	Unusually hot days, droughts, and strong hurricanes, are associated with global warming, and unseasonably cold or rainy days are evidence that global warming is not happening.	Extreme weather conditions, when averaged with conditions recorded over a time span of 30 or more years, have only a small effect on measurements that represent climate.
Climate predictions	Climate is long-term weather and cannot be predicted as weather cannot always be predicted accurately.	Predictions for climate and weather are both based on quantifiable physical systems. Computer models for both these systems represent reality accurately enough to facilitate increasingly accurate predictions for future weather and climate.

Ask Your Students

1. What is the difference between climate and weather?
2. If you have a really snowy winter, does that mean your climate is changing? Why or why not? In what ways might distinguishing weather from climate help students better understand climate change?
3. Why can scientists make predictions about climate, even though weather forecasters are sometimes wrong about their weather predictions?

14 The Climate System and Greenhouse Effect

Student Thinking

The purpose of **Student Thinking** features is to help you prepare for the challenges students may face as they learn about these topics. Common student ideas are compared alongside scientific concepts or are situated in real-life classroom scenarios. Provided quotes come from real students. Suggestions for questions to ask your students are also provided. Accessing student ideas through formative assessment is a great way to learn about your students' knowledge and pique your students' interest in learning more about a topic. Students love to share what they know! You can use what you learn to help guide your teaching. You may find that you need to provide experiences for students that help them confront their existing ideas and begin to develop more scientific conceptions.

1 The Climate System and Greenhouse Effect

by Lindsey Mohan and Jenny D. Ingber

"Climate is what you expect, weather is what you get."
Robert A. Heinlein

Earth's global climate is changing, bringing numerous changes to the planet and the organisms that live on it. Validated records from instruments around the world show that our global temperature increased by around one degree Celsius (almost two degrees Fahrenheit) during the second half of the 20th century. Consequences of this observed warming include substantial melting of glaciers, rising sea levels, and increased risk of drought, wildfires, and plant and animal extinctions.

In order to make well-informed decisions that will enable humans and other organisms to continue to thrive on Earth into the future, today's students need to have at least a basic scientific understanding of our planet's climate system and the role that humans are playing in changing it.

The climate system encompasses a complex set of processes that affect conditions around the world. One of the most important features of the climate system—the **Greenhouse Effect**—is necessary for life on Earth. However, human-induced amplification of this natural phenomenon is now causing a range of changes throughout Earth's system.

In this chapter we consider the differences between climate and weather, look at the climate system in more detail, discuss what it means for climate to change, and take a closer look at the Greenhouse Effect and what students know about this important phenomenon.

Our Experience of Climate

Weather and **climate** are a part of our daily lives. Throughout history, human settlement patterns and

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.a 3.2.b	
Grade 4		
Grade 5	5.4.a 5.4.c-d	
Grade 6	6.3.d 6.4.a-b,d-e	
Grade 7	7.6.a 7.6.f	
Grade 8		

migration routes show that climate has a profound influence on where humans live and how they interact with Earth. Historically, populations in milder climates have thrived relatively easily compared to those that settled in more extreme polar or desert regions. A region's climate controls the types of plants and crops that can grow there and, in turn, the types of animals that the plant life can support. Today, we still see an effect of climate in the "snowbird effect," the annual retreat of retired people from northern latitudes to more southerly ones that allow them to avoid harsh winter conditions.

Our experience of climate is often confused with our experience of weather. Weather is the observable state of the atmosphere at a given time and place. You can step outside your door to see what your weather is right now. If you check a thermometer and note how it feels outside, you can come up with a fairly complete description of your current weather. Weather is highly variable: it can change within minutes and be different in places that are only a short distance apart from one another. Measurements of temperature, precipitation, wind, humidity, and pressure are all a part of weather.

Climate, unlike weather, is a *concept* rather than an observable phenomenon. To make a complete description of your current climate, you would need to consult historical weather records and calculate average values for parameters such as temperature and precipitation.

Climate is the long-term average of weather conditions experienced at a location over a period of 30 years or more. **Climatologists** often use the last three decades (for instance, from 1981 to 2010), or the 100-year period from 1901 to 2000, as a base period to calculate average climate values. Descriptions of climate sometimes focus exclusively on average temperatures, but average values for precipitation and other weather parameters are also part of a location's climate.

The natural vegetation that thrives in a place can be a good indicator of its climate. For instance, if you see desert vegetation in a location, you can infer that its climate is hot and dry. If a place has the lush vegetation of a rain

CHAPTER OVERVIEW

Weather is the current state of the atmosphere at a given time and place. Climate, on the other hand, is the statistical average of weather over a long period. This distinction gave rise to the common phrase, "climate is what you expect, weather is what you get."

Understanding climate change involves understanding both climate norms and deviations from that norm over time. When changes start becoming usual across many decades, one can say an area's climate is changing.

The Greenhouse Effect is necessary for life on Earth, but students struggle with understanding this effect, and the gases responsible for the life-sustaining conditions on Earth. Students also confuse the Greenhouse Effect with climate change and with ozone depletion.

forest, you can deduce that its climate is warm and wet. Latitude, elevation, and proximity to features such as mountains, deserts, and bodies of water are the major factors that control a location's climate. In general, places at low latitudes and elevations are warmer than high latitudes and elevations. Being close to or far from different types of geographic features can affect climate in a range of ways.

Weather is the observable state of the atmosphere at a given time and place.
Climate is the long-term average of weather conditions a place has experienced.

Calculating Climate. The climate for a location on a specific day of the year can be calculated from long-term records of weather. For example, you could look up the average temperature observed on June 1 in each of the last 30 years, and then average the values together. Similarly, you could look up precipitation amounts, humidity levels, cloud cover, and wind speeds observed on that date over the previous 30 years and calculate average values for each of those parameters. The set of average values you end up with from this exercise would be a valid description of the climate for that location on June 1. (Climatologists also calculate other statistics from the records, including measures that indicate how much the individual values vary from the average.)

The 30 separate temperatures you found in the records would span a range of values, reflecting the natural variability of weather over time. For instance, the weather on June 1 of some years may have been cool and stormy. Other years, the date may have been unusually warm. Because climate descriptions report the arithmetic mean, or average, of all the temperatures, the resulting average represents all the conditions that occurred. The value you calculate shouldn't be considered as a prediction of the temperature for the next June 1, but in a stable climate, the average from the past 30 years would provide a good idea of the next value.

Two girls shelter themselves from the rain in Bali, Indonesia.

Students (and adults!) who don't understand the difference between weather and climate can develop incorrect ideas about climate when they experience warmer-than-average or cooler-than-average weather. Daily weather rarely matches the long-term average values for climate, but some people mistakenly believe that any deviation in weather from the average climate is evidence of a cooling or warming climate. When measurements of extreme weather are averaged into a 30-year period that defines climate though, each event accounts for just 1/30 of the calculated average, so single weather events are not considered as indicators of climate, no matter how unusual they may be.

A convenient way to communicate how weather compares to climate is to express weather measurements as the difference between observed conditions and the long-term average, or "normal" value, of the same conditions. Values that represent the difference between observed weather and normal climate values are called **anomalies.**

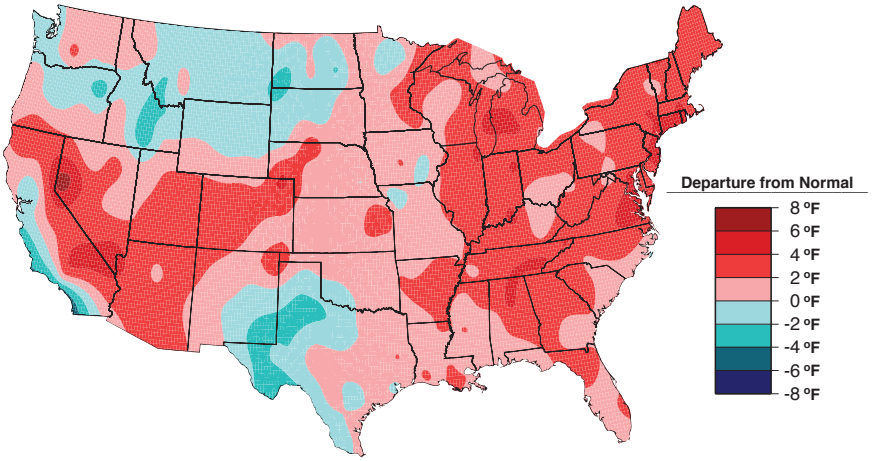
When the Unusual Becomes Usual

Scientific organizations such as the Intergovernmental Panel on Climate

Scientists study many of the same variables to learn about weather and climate, and climate is determined by long-term averages of these variables.

JULY 2010 TEMPERATURE ANOMALIES

Departures from the 1971—2000 Normal



This map shows how much warmer or cooler locations in the contiguous United States were during July of 2010 compared to their average temperatures during July from 1971 to 2000.

Red areas on the map show locations that were warmer than average, and blue areas show locations that were cooler than average (National Climatic Data Center, U.S. Climate at a Glance).

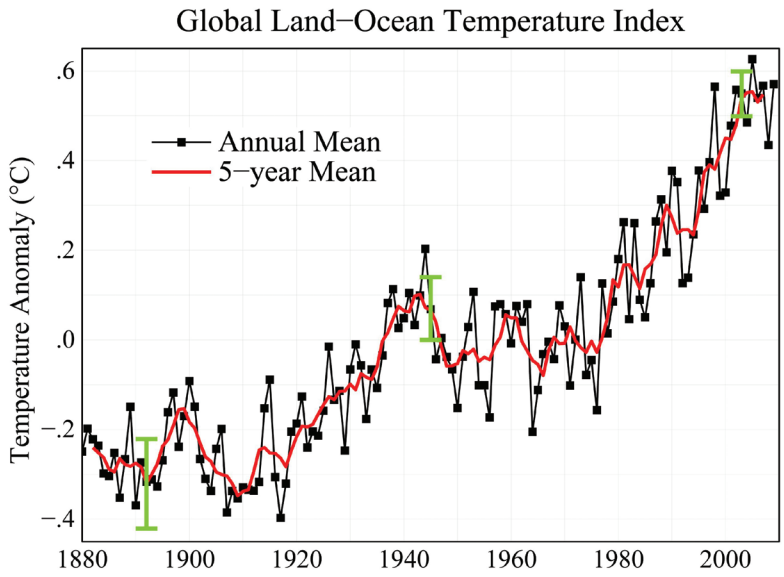
Change (IPCC) and the UN Framework Conventions on Climate Change (UNFCCC) have developed carefully worded definitions for ***climate change.*** Using the common elements of these organization's definitions, climate change is a change over time in the location's climate, indicated by changes in patterns of average temperature, precipitation, and other parameters, or the variability of these patterns. To be considered as climate change, observed changes need to be larger than changes that can be attributed to natural variation, and the change must persist for an extended period, usually decades or longer.

For educators, a useful way to describe climate change is *when the unusual becomes the usual.* This statement reflects the fact that when climate changes, the new conditions (the unusual) become more common that the historical average conditions (the usual). When the unusual becomes usual over time, statistical averages, scientific evidence, and anecdotal stories told by local residents will converge to tell the same story—the climate has changed.

A valid way to identify a changing climate is to calculate climate averages for a base period of at least 30 years, and then compare those values to averages calculated for an earlier or later period of the same length. Mathematical techniques can reveal if differences between the averages from two different periods are large enough to be "statistically significant," or if they are so small that they don't represent real change.

Consider that most of Florida has a subtropical climate: It is generally warm and wet, with a good chance for afternoon thunderstorms in the summer. Occasionally, a single summer or a string of three or four summers might be cooler than normal, with fewer thunderstorms than average. This situation would not mean that Florida's climate is no longer subtropical. If, however, Florida's annual average summer temperatures were lower than normal for 20 or 30 years, its long-term average temperature would be lower than in the past, and people would recognize that its climate was changing to become more temperate.

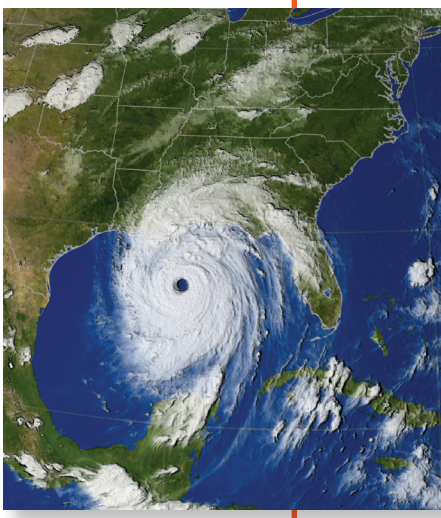
GLOBAL TEMPERATURE



Scientists have graphed global temperature averages each year, and the average over time shows a general trend toward warming temperatures.

Student Thinking

Climate and Weather



It is challenging to untangle our experience of weather from our experience of climate. Students may use the terms *weather* and *climate* interchangeably, or they may perceive extreme weather events as indicators of climate change. For example, when Hurricane Katrina hit New Orleans and the Gulf Coast in 2005, many people considered the storm as evidence of a changing climate. However, historical records show that locations in the Gulf commonly experience several hurricanes per century and that some years have more of these monster storms than others. Though the number of hurricanes that made landfall in the Gulf during 2005 was significantly larger than the historical average, it remains to be seen if this trend will persist into the future.

	Common Student Ideas	Scientific Ideas
Climate* versus *weather	The terms *climate* and *weather* can by used interchangeably	*Climate* is the average (mean) of climate variables over 30 years or more. *Weather* is the observable state of the atmosphere at a given time and place.
Weather	Unusually hot days, droughts, and strong hurricanes, are associated with global warming, and unseasonably cold or rainy days are evidence that global warming is not happening.	Extreme weather conditions, when averaged with conditions recorded over a time span of 30 or more years, have only a small effect on measurements that represent climate.
Climate predictions	Climate is long-term weather and cannot be predicted as weather cannot always be predicted accurately.	Predictions for climate and weather are both based on quantifiable physical systems. Computer models for both these systems represent reality accurately enough to facilitate increasingly accurate predictions for future weather and climate.

Ask Your Students

1. What is the difference between climate and weather?
2. If you have a really snowy winter, does that mean your climate is changing? Why or why not? In what ways might distinguishing weather from climate help students better understand climate change?
3. Why can scientists make predictions about climate, even though weather forecasters are sometimes wrong about their weather predictions?

The Climate System

When talking about climate, most people think about the climate of a familiar region. They can visualize how rainy their region is during summers, and know what type of weather to expect in the winters. Understanding the climate of a single place—likely the place where they live—is the first step in comprehending the enormity of what is meant by global climate. Climate is studied and measured at a very large scale, ultimately encompassing the entire Earth system, and over long periods of time, from decades to centuries.

Earth comprises five overlapping, interacting materials called spheres. These include

- **atmosphere**—gases that surround Earth's surface
- **biosphere**—all of the living organisms on Earth that live both in the water and on the land
- **cryosphere**—frozen water on Earth, found as accumulations of snow and ice in glaciers, sea ice, and ice sheets such as those found in Antarctica and Greenland
- **geosphere**—the rocky part of Earth, including mountains, rocks, and soil, as well as layers of molten material inside the planet
- **hydrosphere**—all the water on the planet, on the surface , underground, and in the air

Matter and energy are constantly changing forms and moving among these five spheres. Probably the most familiar example of matter moving through these spheres is demonstrated by the water cycle. Water can move from the hydrosphere to the atmosphere through evaporation, then condense and fall back to Earth as snow, becoming part of the cryosphere. Once the snow melts and flows into a river, it is part of the hydrosphere again. If an animal drinks it, the water becomes part of the biosphere. Water

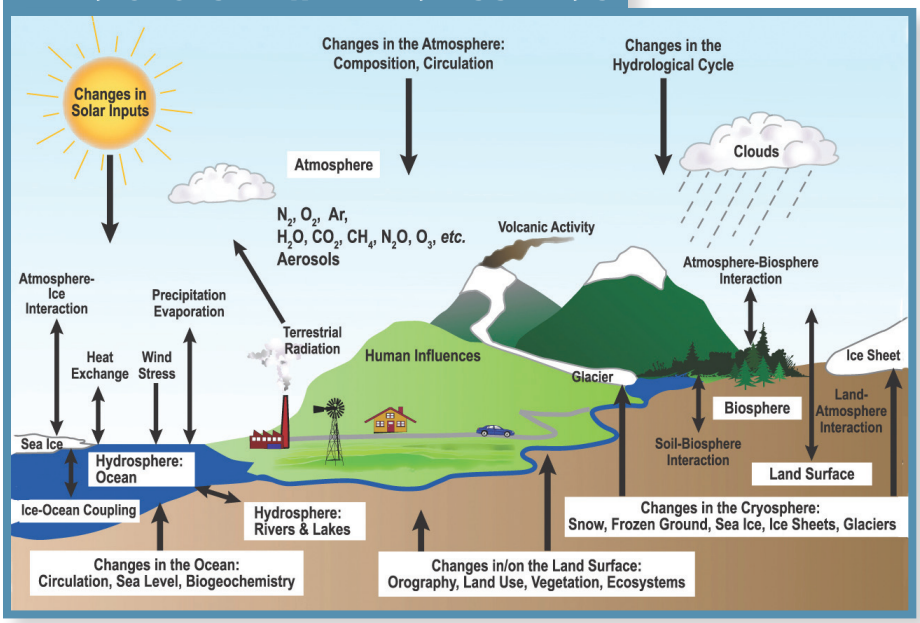
A storm develops off the coast of Eleuthera, the Bahamas, circulating water through the atmosphere and hydrosphere.

doesn't always move through the cycle linearly. Rather, it can move to more than one other sphere at several steps, and processes can move it in both directions through the cycle. This complexity is representative of a system.

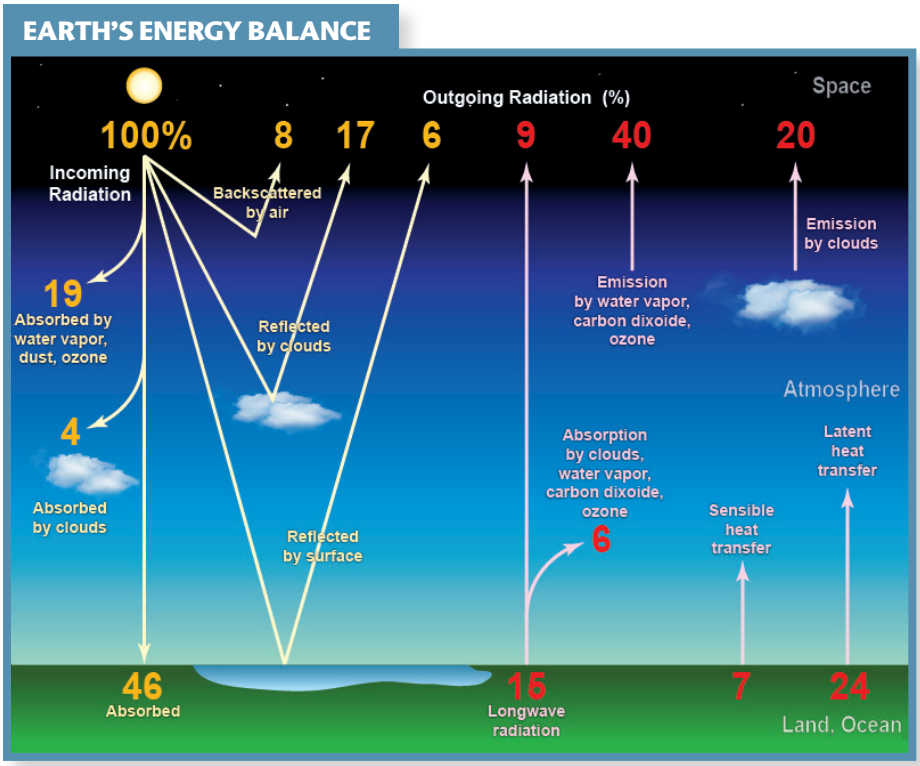
The reason climate is discussed as a "system" is because of the dynamic, continuous movements of matter and energy among its different components. Looking at all of the spheres on Earth and the way matter and energy moves among them provides a convenient way to understand the climate system.

To describe the cause of present-day climate change, one can tell a simple, but helpful story about how materials have moved through Earth's spheres over time. Over hundreds of millions of years, large amounts of carbon, once located in our atmosphere, were incorporated into growing plants and sequestered in the biosphere. Eventually, the plants died, and the carbon they contained was transformed into fossil fuels such as coal and oil in the geosphere. Now, humans are retrieving these fossil fuels and burning them to power transportation and industry, returning huge amounts of carbon back to our atmosphere in a fraction of the time the carbon took to accumulate in the biosphere. The increasing amount of carbon in the atmosphere has increased the amount of heat energy the atmosphere absorbs and releases at Earth's surface. The result of changes in the atmosphere is a series of ongoing and cumulative changes in the cryosphere, hydrosphere, biosphere, and geosphere. Collectively, these changes are known as global climate change.

INTERACTIONS BETWEEN EARTH'S SPHERES



This illustration details the different interactions between the Earth's spheres. Notice that each sphere interacts with others in multiple ways, creating a complex web of relationships.



A sample energy balance shows how scientists quantify the incoming and outgoing radiation.

Teaching Tip

One way to help students understand energy is to encourage them to create an energy story line. An energy story line traces how energy changes form as it interacts with matter on or near Earth's surface. When teaching about Earth's global energy balance, help students build a story about how the sun's energy changes forms when it interacts with air and land surfaces. An example storyline might look like this:

The sun's rays give off solar radiation. → Rocks, soil, and water convert light energy into heat energy. → Differences in heat energy at Earth's surface result in wind, or kinetic energy. → Kinetic energy of wind turns turbines, ultimately changing into electrical energy. → Electrical energy turns into light energy and heat when people turn on lightbulbs.

Earth's Energy Balance

We burn fossil fuels such as oil, natural gas, and coal to obtain the energy that was trapped in the chemical bonds of those fuels. However, the primary source of the vast majority of energy on Earth is the sun. The sun continuously emits energy into space in the form of electromagnetic radiation. When this energy reaches Earth's atmosphere and surface, it interacts with matter in the air, ocean, land, and life. In these interactions, solar radiation from the sun can be converted into other forms of energy such as heat and chemical energy. For example, **photosynthesis** in plants converts solar radiation into chemical energy by incorporating it into the bonds of carbon-based sugar molecules. Rocks and soils can absorb solar radiation and convert it to infrared radiation, or heat—which explains why Earth's surface gets warm when it's in direct sunshine. The heat energy emitted by Earth interacts with gases in the atmosphere, creating differences in the density of air at different locations and resulting in winds.

Examining the balance between incoming solar radiation (energy from the sun) and outgoing longwave radiation (the heat given off by Earth's surface) will help us understand our planet's climate system. We will explore this balance in the context of Earth's **energy budget.**

As energy from the sun reaches our planet, some of it is reflected out to space; the remaining energy enters Earth's system and interacts with gases in the atmosphere and materials at the planet's surface.

Most of the energy that arrives as ultraviolet (UV) rays, gamma rays, and x-rays interacts with gas molecules in Earth's upper atmosphere and is released in a different form. One result of these interactions is that Earth's surface is protected from these life-damaging

forms of energy. Without this shield of gases, life would probably not exist on Earth.

Incoming radiation that moves through the upper atmosphere can also be reflected back into space. That is why clouds, ice, and large desert areas are so bright in a picture of Earth from space: these materials are reflecting solar energy away from the planet.

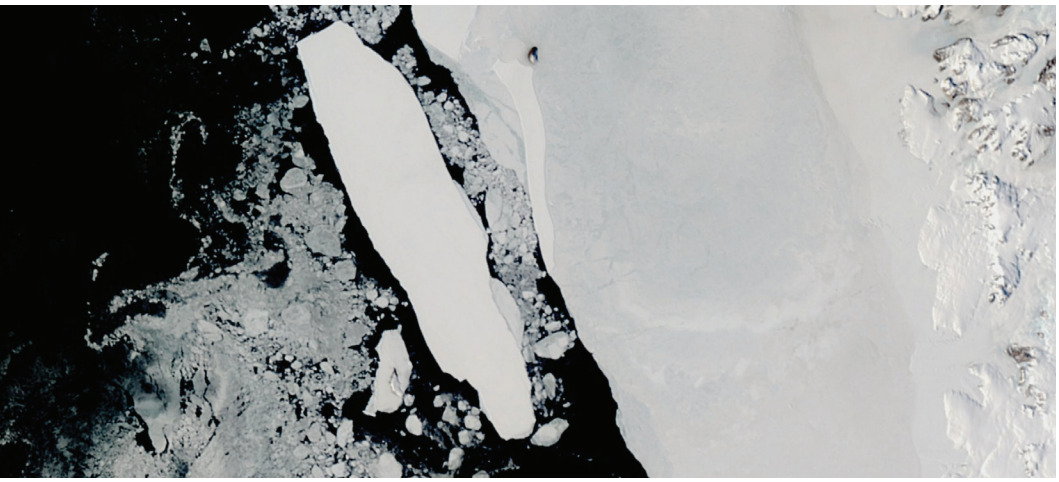
When incoming radiation is absorbed by materials at Earth's surface, some of the radiation is reemitted as infrared radiation, or heat. Heat is invisible to our eyes, but we can feel it, and it continues to interact with other materials at or near Earth's surface, including gases and aerosols in the atmosphere. **Global radiative balance** is a concept that has been studied and explained by physics. It states that any system that is in balance must emit exactly as much energy as it receives. To be in balance then, Earth must emit the same amount of energy (mostly as heat) into space as it receives as solar radiation from the sun.

Albedo Effect. ***Albedo*** is a term that describes the amount of incoming radiation that is reflected by matter. Surfaces that are highly reflective, such as a mirror, or light in color, such as snow, have high albedos. Darker materials such as plants and dark soils have lower albedos. These low-albedo surfaces absorb more of the solar energy that hits them than the higher albedo surfaces do. Albedo is a practical concept. For example, people in hot, sunny regions often choose light colors for their clothes because light colors absorb less energy in direct sunlight than dark colors, ultimately keeping them cooler.

On a large scale, albedo has important implications for climate change. Snow and ice are highly reflective surfaces. Up to 95 percent of the solar radiation that hits bright white surfaces of fresh snow and ice is reflected back from the surface, and this energy is essentially unchanged. When ice melts, though, a surface of liquid water has a lower albedo, so it absorbs a higher percentage of incoming solar radiation. As a consequence of the decrease in albedo as water changes from a solid to a liquid, the more ice that melts, the more energy becomes available to melt more ice.

Earth's Natural Greenhouse

Our atmosphere plays an important role in maintaining Earth's energy balance. The way different gases in it interact with incoming and outgoing radiation is key to understanding how life on Earth exists.



Water and ice have different albedo. The image shown shows water that will absorb more incoming radiation compared to snow or ice that will reflect more radiation.

For the most part, gases in the atmosphere allow incoming solar radiation to pass through and reach Earth's surface. As Earth emits this energy as heat, however, some gases in the atmosphere interact with the energy in ways that keep some of the energy near Earth's surface instead of releasing it into space. These gases—referred to as greenhouse gases—absorb heat energy and reemit it in all directions, sending some of it back toward space but returning much of it to other molecules in the atmosphere or materials at Earth's surface. Life, as we know it, is dependent on this process. The phenomenon is known as the Greenhouse Effect, named for its similarity to processes that allow greenhouses to be effective environments for growing plants when outside temperatures are too cold.

Water vapor is the most abundant greenhouse gas on Earth. We refer to the amount of water vapor in the air as humidity. Our experiences in humid and arid climates can help us understand how greenhouse gases relate to temperature changes.

Deserts generally have low humidity. Have you ever been to a desert region and noticed how much cooler it gets at night compared to the day? In contrast, regions that have high humidity don't experience as large a difference in their daytime and nighttime temperatures. Summer days in deserts across the American Southwest can top 43°C (109°F), but nighttime temperatures can drop into the 20s C (70s F) as outgoing radiation escapes to space. However, residents of Florida, for example, often experience humid summer days during which temperatures reach 32°C (90°F). Though heat energy has an opportunity to escape all through the night with no additional solar radiation coming in, morning temperatures are usually still around 27°C (81°F). The large amount of water vapor (high humidity) in the air

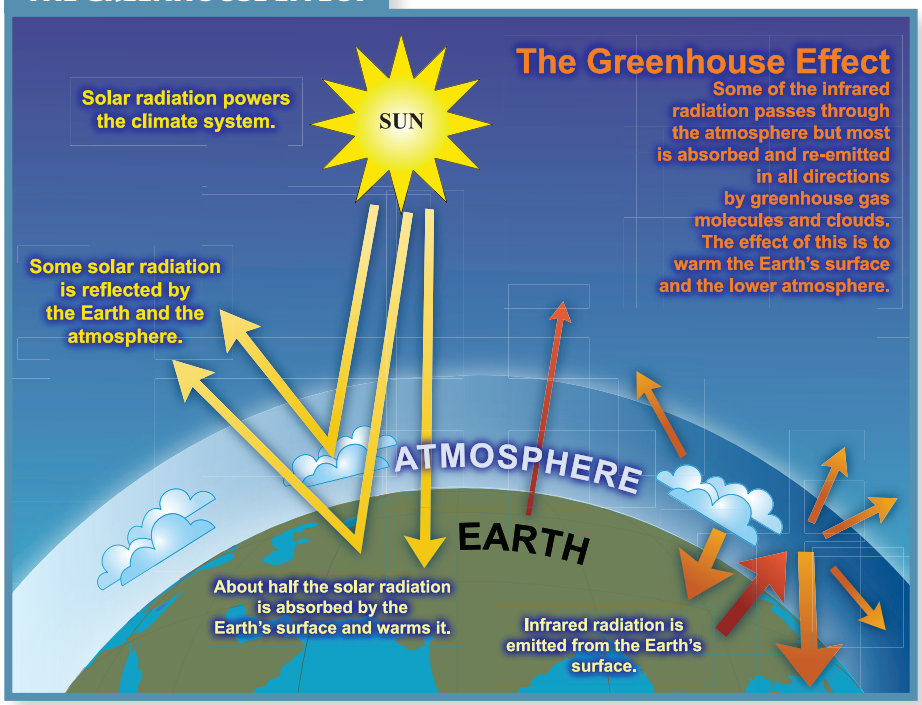
in this region essentially "traps" much of the outgoing infrared radiation by absorbing it and continually reemitting it to its surroundings. The amount of water vapor in the air varies greatly over time and space.

Beginning in the 1930s, scientists led by Dr. Guy Stewart Callendar, and later, in the 1950s, scientists led by Dr. Charles Keeling, began to monitor concentrations of greenhouse gases in our atmosphere. Dr. Keeling began monitoring carbon dioxide levels at NOAA's Mauna Loa Observatory in Hawaii in 1957, and the monitoring continues today. Mauna Loa was selected because of its large distance from land and cities that may influence the mixture of gases in its samples. Data collected at Mauna Loa—sometimes referred to as the Keeling curve for the shape it makes on a graph—shows that carbon dioxide levels increased from approximately 315 ppm (parts per million) in the atmosphere in 1957 to roughly 390 ppm in 2010. Data collected at the South Pole and other stations around the world agree with findings from Mauna Loa.

Increasing Carbon Dioxide in the Atmosphere. For the past several thousand years, humans have been reducing the amount of Earth's land that is covered by forests to obtain fuel and increase the area they have for building cities, growing crops, and raising animals. As forests have decreased, their ability to absorb carbon dioxide from the atmosphere has decreased. During this period, however, Earth was experiencing a gradual, natural cooling trend.

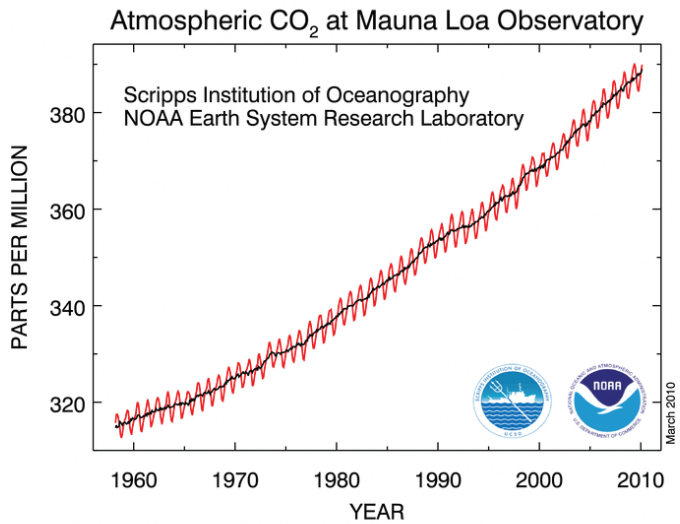
In recent years, the rapid increase in the amount of atmospheric carbon dioxide entering the atmosphere has been attributed to human use of fossil fuels. Rising levels in other greenhouse gases such as methane and nitrous oxide are also attributable to human activities. Scientists do not know for certain when human actions began to influence atmospheric carbon dioxide levels at the global level. However, it is now clear that the cumulative effects of increasing the amount of carbon dioxide through the burning of fossil fuels and decreasing the amount of carbon that the biosphere can remove from the atmosphere by clearing forests are attributable to human activities. It is important to note that Earth does experience natural warming and cooling trends caused by changes in the Sun or volcanic activity, but present-day climate change is mostly attributed to human activities.

THE GREENHOUSE EFFECT



The Greenhouse Effect describes how our Earth maintains habitable temperatures by the balance between incoming and outgoing radiation.

CARBON DIOXIDE MEASUREMENTS



This graph shows measurements of atmospheric carbon dioxide levels from the Mauna Loa Observatory in Hawaii, a location that has measured CO_2 levels since the late 1950s.

Student Thinking

Greenhouse Gases

Students struggle to understand gases as a form of matter. While students may be able to recite that matter comes in three forms—solid, liquid, and gas—they treat gases as quite different from solids and liquids. It can be a challenge for students to understand that although gases are invisible, they have mass and take up space. Many students have difficulty understanding the effect of greenhouse gases because they don't have a strong grasp of gases as real, tangible materials (Gowda et al. 1997; Jacoksson & Saljo 2009). When looking at greenhouse gases in particular, they may believe that these gases are bad because they are linked to climate change (Andersson & Wallin 2000). Most greenhouse gases are natural and necessary for life on Earth.

Scenario

You have just finished a lesson on greenhouse gases and want to see if your students learned the main concepts. You ask the class to discuss the following question as a summary to the day's lesson.

Question

Are greenhouse gases—carbon dioxide in particular—good or bad?

Scientific Answer

Greenhouse gases are essential to life on Earth (see **Earth's Natural Greenhouse,** page 17). This means that greenhouse gases are needed in the atmosphere to regulate temperatures to sustain life. While water vapor is the most important greenhouse gas, carbon dioxide is also important because of its necessary role in photosynthesis. An amplification of greenhouse gases, as is seen today, can alter atmospheric temperatures.

Student Answers

Sarah: I think carbon dioxide is a bad gas, even though it's helping us. So in different ways, it's a bad gas because it does so many bad things to us. But it's helpful if you have the right proportion of it, if you go overboard.

Thomas: I know there are greenhouse gases that aren't necessarily good for us. And a big one I think is carbon dioxide cause it's not that great for us.

Jacob: Because greenhouse gases pollute the world like carbon dioxide.

Joyce: It's good and bad, because trees get carbon dioxide and they need it, and they give us oxygen, but carbon dioxide is also bad because when we inhale it, it's bad for our bodies.

What Would You Do?

1. What patterns do you notice in students' answers?
2. How would you reteach the lesson to ensure more students understand the difference between naturally-occurring greenhouse gases, and amplified greenhouse gases?

Pictures of Practice

Greenhouse Gases: Good or Bad?

The struggle to understand greenhouse gases arises because of challenges in learning about gases, as well as challenges in learning the difference between the natural Greenhouse Effect and an enhanced Greenhouse Effect. While many people understand that the Greenhouse Effect is natural, they may also associate greenhouse gases with global warming, and, therefore, label these gases as bad. Yet, life on Earth evolved in a certain way because of how these gases regulate Earth's temperature.

Students: Grade 6

Location: South Gate, California (an urban community)

Goal of Video: The purpose of watching this video is to see students share ideas about the role of greenhouse gases on Earth.

Classroom Context

Ms. Walker, a sixth-grade teacher, engages her students in a discussion about the role of greenhouse gases in our atmosphere. Ms. Walker teaches in a large, urban school district, and her students in the video qualify for gifted and talented (GATE) placement. Ms. Walker explained that while this class was primarily GATE students, there was still a wide range of understanding among students with respect to science. Her students share both correct and incorrect ideas about science topics throughout the year, and the same was true during her unit on climate change. The lesson on greenhouse gases occurred in the middle of her two-week unit on climate change.

Video Analysis

Greenhouse gases are necessary for life on Earth because they help regulate Earth's temperature. However, some students may associate greenhouse gases with global warming, and, therefore, say that greenhouse gases are bad. At the beginning of the video, Ms. Walker predicts that some of her students will believe greenhouse gases are "bad" for the environment. She believes her students have made the link between these gases and global warming but still misunderstand how these gases regulate Earth's natural greenhouse. In the preinterviews Emily confuses the natural Greenhouse Effect with the amplified Greenhouse Effect (global warming). During the classroom discussion, Emily begins the discussion by saying she thinks greenhouse gases are bad because they get trapped in the atmosphere. Christopher describes greenhouse gases as being good for plants, and Amaya chimes in that greenhouse gases are both good and bad, but only Valeria seems to understand that greenhouse gases regulate Earth's temperature. Eliazar particularly struggles with understanding greenhouse gases and the Greenhouse Effect, as seen when the teacher quizzes him at the end of the lesson.

Reflect

How could you help students understand greenhouse gases and the Greenhouse Effect?

Think about how you would respond in a situation in which students believe greenhouse gases are bad. How would you convince them that greenhouse gases are natural and necessary? Why do you think Eliazar continues to have questions about greenhouse gases? For your instructional plans, consider teaching about the natural greenhouse effect before introducing students to amplified warming and climate change.

Representations of Science

Analogies for Greenhouse Effect

The Greenhouse Effect was named for its similarities with what we observe with greenhouses. The plastic or glass roof and siding of garden greenhouses have properties that are similar to greenhouse gases in our atmosphere. The transparent roof allows incoming solar radiation to enter the greenhouse, yet blocks outgoing infrared radiation (heat) from exiting. The result is a net warming inside the greenhouse, which enables plants to grow during times when exterior temperatures are too cool. When temperatures become too warm inside the greenhouse, the gardener can open vents in the greenhouse, allowing some of the warmed air and excess infrared radiation to escape.

A garden greenhouse provides a tangible, real-world example to help students make sense of abstract phenomena, such as the Greenhouse Effect, that involve invisible gases interacting with invisible radiation. Educators can even find a local greenhouse to take students to visit, or students may bring in their own experiences about greenhouses to share with their peers. Leveraging these experiences and using the concrete analogy of a gardening greenhouse are useful strategies for helping students understanding the general concepts of the Greenhouse Effect.

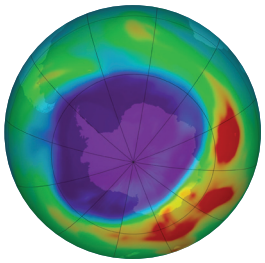
However, the greenhouse analogy can also lead to unexpected misconceptions among students. Like all analogies, the greenhouse has its limits. The interior of greenhouses are also warm because they provide shelter from outside weather, especially wind, which is not captured in the analogy. Likewise, greenhouses have vents that can be opened and closed depending on the desired temperature.

Climate Change and the Ozone Hole

Ozone is a gas found in Earth's upper atmosphere, as well as closer to its surface. Like the oxygen molecules we depend upon for breathing, ozone is composed solely of oxygen atoms. The difference is that oxygen molecules have two oxygen atoms and ozone molecules have three. In our upper atmosphere, ozone provides a critical service for life: It acts as Earth's natural sunscreen and blocks some of the ultraviolet radiation that comes from the sun, shielding us from damaging rays. Beginning in the late 1970s scientists began to measure ozone and found that the thickness of the **ozone layer** in the upper atmosphere was lower over the southern polar region during the months of September through January. This phenomenon is now referred to as the **ozone hole**. Scientists discovered that **chlorofluorocarbons** (CFCs) and similar chemicals were causing ozone molecules in that region to break down. In 1987, countries from around the world signed the Montreal Protocol, agreeing to restrict their emissions of these chemicals. Over the past 25 years, scientists have observed a reduction in the concentrations of the substances that were depleting ozone, and they expect the ozone layer to recover over time.

At lower altitudes, close to Earth's surface, ozone gas is a hazard to the health of people and other organisms. Ozone has been linked to problems with asthma and other respiratory issues in humans, and it affects the health of crops and other plants. Ozone at this level in the atmosphere is a key component of "smog" that plagues cities, with emissions coming mostly from industrial processes and cars.

In one study of student understanding of climate change, a student described causes of climate change in this way: "Driving trucks releases carbon dioxide like hairspray, which puts holes in our ozone. Electricity also puts holes in our ozone." (Mohan et al. 2009). Other students have claimed that carbon dioxide breaks down the ozone layer or that cars cause the ozone hole. These are fairly prominent misconceptions among both youth and adults and, therefore, deserve particular attention when teaching about climate change.

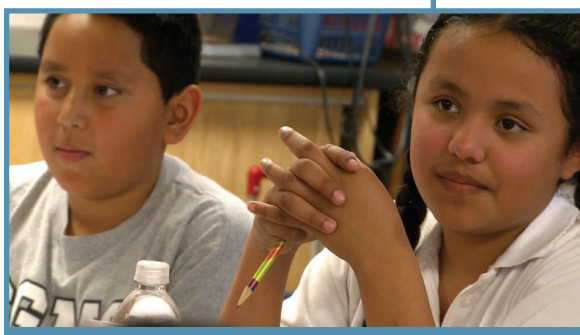


The ozone hole occurs over Antarctica and is actually a thinning of ozone in the upper atmosphere.

Pictures of Practice

Greenhouse Gases and the Ozone Hole

Teachers use analogies, metaphors, and models to teach about how things work in the world. The greenhouse analogy, for example, provides a visible image to help students understand an abstract concept such as the Greenhouse Effect. By having students discuss what happens in a greenhouse, teachers can help them make sense of how radiation, or heat, could be trapped inside the atmosphere like heat trapped inside a greenhouse. However, this analogy can lead to another misconception about climate change that is connected to confusion about global warming and ozone depletion.



Students: Grade 6

Location: South Gate, California (an urban community)

Goal of Video: The purpose of watching this video is to see how the greenhouse analogy brings out misconceptions about the ozone hole.

Classroom Context

Previously, Ms. Walker taught her students about climate change in detail, but many students were struggling with understanding greenhouse gases and how they influence temperature in the atmosphere. Prior to the current lesson, some students had mentioned the ozone hole during discussions, claiming that greenhouse gases cause the ozone hole. Ms. Walker set this concept aside to continue her work on the greenhouse effect but, at the end of the week, realized that her students still had misunderstandings about the phenomena.

Video Analysis

The greenhouse analogy provides a concrete, real-world representation to help students make sense of the greenhouse effect, which can seem like an abstract concept. Like the Earth's greenhouse gases, the garden greenhouse structure absorbs radiation that would normally escape into the air around the greenhouse. In this video, you will see Ms. Walker review the greenhouse analogy with her students. The students had already learned about how gardening greenhouses work, and Ms. Walker used this discussion as a reminder. With help from Emily, Ms. Walker describes the gardener as opening up windows to let out excess heat from the greenhouse. She goes on to explain that there are no "windows" in the atmosphere that we can open to let the heat out. Cristabel, however, asks, "Why can't greenhouse gases escape through the ozone hole?" During her reflection, Ms. Walker shares her surprise by Cristabel's question, stating that they had never talked about the ozone in previous classes.

Reflect

If Cristabel said this in your classroom, what would be your next step?

Think about the trade-offs of the greenhouse analogy and how this analogy led to Cristabel's confusion. If you had been in Ms. Walker's shoes, how would you respond in this situation? How can your instructional plans take into account the potential drawbacks of the greenhouse analogy, as well as students' misconceptions about greenhouse gases and the ozone hole? Consider having your students do activities in which they contrast the ozone hole with climate change, so they learn the important differences.

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"Winter 2009–2010 Weather Statistics for Washington/Baltimore—February 2010." 2010. NOAA: National Weather Service. www.nws.noaa.gov/os/presto/2010febtable.pdf. June 8, 2010.

Teaching Resources:

California Education and the Environment Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm

Carbon Dioxide Measurements and Data: http://www.esrl.noaa.gov/gmd/ccgg/trends/

Ozone hole data and updates: http://ozonewatch.gsfc.nasa.gov/index.html

NASA animations: http://www.nasa.gov/centers/goddard/earthandsun/climate_change.html

NASA Exploring Albedo Activity: http://eosweb.larc.nasa.gov/EDDOCS/scierbe.html

National Geographic Climate and Weather Videos: http://video.nationalgeographic.com/video/player/science/earth-sci/climate-weather-sci.html

2 The Global Carbon Cycle

by Lindsey Mohan and Jenny D. Ingber

All living things are made of carbon compounds, from the grass you walk on to our human bodies. Since carbon is a major component of all plants and animals, it also comprises the food we eat and the products we make from wood and cotton. Carbon is also present in every breath we exhale. Fossil fuels such as coal, oil, and natural gas are also made of carbon: these natural deposits formed when the carbon compounds of dead organisms underwent chemical changes below Earth's surface. All of these carbon compounds—both foods and fuels—are important to human communities because we depend on them to meet our needs for energy.

One of the products we release when we use carbon compounds is carbon dioxide. While carbon dioxide is invisible to the human eye, increasing amounts of this gas are now affecting our world's global temperature, and in turn, our atmospheric circulation patterns and global climate.

The processes that move carbon through and around our world are part of the **global carbon cycle.** Similar to the familiar cycle that moves water between its solid, liquid, and gas forms, the carbon cycle involves common science processes that students commonly learn in school: these include photosynthesis, cell function, and **combustion,** to name just a few. The need to increase student understanding of the products and processes of the carbon cycle is becoming urgent, as global-scale changes in the amounts of carbon in different parts of the carbon cycle are now resulting in global climate change.

Carbon Around Us

You may have heard that diamonds are made of carbon. Did you know that graphite—the soft, gray material that forms the "lead" of a pencil—is also made of carbon? How can these two materials be made of the same kind of atoms but look and feel so different?

The name for different materials composed of the same kind of atoms is **allotrope.** Thus, diamond and graphite

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.b	
Grade 4	4.1.3-5 4.2.a-c	Reflections of Where We Live; Plants: The Ultimate Energy Resource The Flow of Energy Through Ecosystems Life and Death with Decomposers
Grade 5	5.1.h 5.2.b,e-g	
Grade 6	6.1.3 6.5.a-b	
Grade 7	7.1.d	
Grade 8	8.12.1 8.12.5 8.6.a-c	Agricultural and Industrial Development in the United States (1877—1914) Industrialization, Urbanization, and the Conservation Movement

are both allotropes of carbon. The difference in the materials is that at a very small scale—detectable only under the most powerful types of microscopes yet invented—their atoms have different arrangements. The atomic-scale differences result in visible differences in appearance and characteristics. For instance, diamonds are colorless while graphite is gray; diamond is one of the hardest minerals found on Earth, but graphite will rub off on your hands. Though these allotropes are very different, they are both made completely of carbon.

If you ask your students for examples of materials made of carbon, they may mention diamond or graphite. If they know that diamond and graphite are carbon, they may recognize that both materials are part of the carbon cycle. Diamond and graphite, however, move through the carbon cycle at a much slower rate than many other carbon compounds.

Carbon is one of the most abundant elements in the known universe, and its atoms readily form chemical bonds with many other elements. The result is that the world has an incredible range of carbon compounds. One of the simplest

CHAPTER OVERVIEW

The carbon cycle describes how carbon moves in and out of reservoirs on our planet. Where carbon is located, and in what form, is important for understanding climate change. For much of Earth's history, enormous amounts of carbon have existed as coal and oil (fossil fuels). As humans learned to use these materials as fuels to power transportation and industrial manufacturing, the carbon is being moved relatively quickly into the atmosphere as carbon dioxide.

Places where carbon accumulates are known as carbon "sinks" or "reservoirs." For instance, a growing forest removes carbon from the atmosphere and stores it in the structure of its wood and leaves. The opposite case, a carbon "source," is something that gives off carbon. One example is a volcano, which erupts carbon dioxide gas along with ash or lava. Scientists track the movement of carbon between sinks and sources. Looking at large-scale systems, they can develop a carbon "budget" to keep track of where carbon is stored and where it is moving.

The carbon cycle is an important part of school curriculum. In this chapter we explore the science of this cycle, and student ideas about how carbon moves through this cycle. We take a closer look at photosynthesis and productivity, sequestration, and combustion of fossil fuels as key processes in the carbon cycle.

and most stable carbon compounds is carbon dioxide.

Carbon Dioxide. Carbon dioxide is becoming well known because of its association with climate change. As such, it is often labeled as a "bad" gas. Yet, life on Earth may not exist without some amount of this gas in our atmosphere.

Every carbon-dioxide molecule is one carbon atom bonded with two oxygen atoms. Its chemical formula is CO_2, one of the first and easiest gases for students to name and remember. While carbon dioxide only constitutes around 0.04 percent of the gas molecules in our atmosphere, it serves as a greenhouse gas that keeps Earth's surface from being frozen solid. It is also necessary for plants, which need carbon dioxide to perform photosynthesis. Without carbon dioxide, plants would not be able to form energy-rich compounds such as sugars and starches.

Organic Carbon. Organic carbon compounds are the materials that make living things. They are mainly composed of carbon, hydrogen, and oxygen atoms, along with traces of other elements. Different combinations of these elements, chemically bonded together in various arrangements, form sugars, starches, and carbohydrates, plus lipids (fats), proteins, and acids (like DNA). Organic carbon compounds also include hydrocarbons, the molecules found in fossil fuels. These substances are rich with chemical energy, originally captured from the sun through photosynthesis. Viewed at the most fundamental level, the material that makes up an apple is very similar to the gasoline we pump into our cars! Both are composed of organic carbon compounds, and both are rich with energy.

Many students know that plants take in carbon dioxide from the atmosphere, but they do not think about how plants use carbon to grow their stems, leaves, and fruits. When animals and decomposers digest those materials, they release the carbon back into the air as carbon dioxide.

Plants are an important part of the carbon cycle, acting as carbon sinks.

This cycle sometimes gets *too* simplified for students. Instead of developing a story about how carbon dioxide moves from a gas into other carbon compounds, students tend to develop ideas about *gas-gas cycles* (Mohan et al. 2009). Gas-gas cycles describe plants changing carbon dioxide into oxygen and animals changing oxygen back into carbon dioxide. When students are asked to explain what happens to the carbon atom during these cycles (i.e., where does the carbon atom go inside of plants, and where does it come from when we breathe it out) some will respond that carbon dioxide is "bad oxygen." Many students do not realize that the carbon entering the plant as part of the carbon-dioxide molecule is being used to make new substances, such as sugar or starch.

The Carbon Cycle

The global carbon cycle is a complex cycle, involving many materials and their movement between many systems. Because carbon moves between materials through biological, geological, and chemical processes, the carbon cycle is known as a **biogeochemical cycle.** Again, the water cycle, which includes processes that move water through living things, rocks, and chemical processes, provides another example of a biogeochemical cycle.

Carbon Atoms Move. Carbon atoms are matter; they cannot be created or destroyed. Carbon can only change form by making chemical bonds with other atoms. A carbon atom that is part of a tree today has a long history of being part of other things throughout Earth's history. The atom could have been part of the muscle of a dinosaur, or the beak of one of the last dodo birds

Teaching Tip

Given that carbon dioxide is associated with climate change and it is the main greenhouse gas monitored by scientists, students tend to make carbon dioxide a villain just as they would the bad guy in a story. Yet, carbon dioxide is an important greenhouse gas that helps to keep our planet habitable. It is also the gas that plants need to live. Be attentive to how students talk about carbon dioxide because although it is one of the greenhouse gases causing climate change, it is also fundamental to life on Earth. Climate change is about having too much carbon dioxide.

that roamed Earth. This means that the carbon that makes up our very bodies has existed in other forms as well.

The movement of carbon happens on two time scales. There is a long-term part of the carbon cycle and a short-term part. The rocky, outer crust of our planet—the outermost portion of the geosphere—plays an important role in the long-term carbon cycle. Many of the rocks (such as coal) and minerals (such as calcite) that make up Earth's crust contain carbon. As rocks and minerals change form as part of the rock cycle, carbon contained within them moves to different places. For example, when weathering processes break rocks into smaller pieces called sediments, streams and rivers carry the sediments to the ocean. After settling on the ocean floor and becoming buried by subsequent layers of sediments, the carbon contained in the original rocks might eventually be melted and erupted to the surface again in a volcanic eruption. Geologic processes such as these require immense stretches of time to move carbon from one place to another.

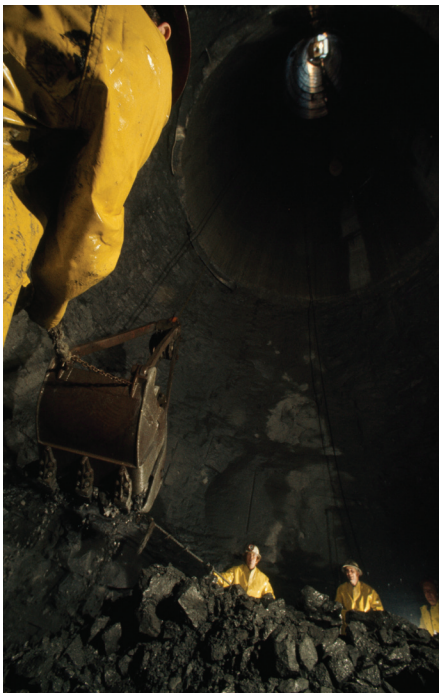
Biological and chemical processes that occur at or near Earth's surface move carbon through various forms on a much faster time scale. Through photosynthesis, carbon moves from the air into plants, and through cellular respiration, decomposition, and combustion, carbon moves back into the air. Movements of carbon through these processes may happen on time scales measured in days.

These two time scales of the carbon cycle—the long-term cycle through geologic processes and the short-term cycle through biochemical processes—can help us understand how the amounts of carbon in different parts of the cycle are changing, leading to global climate change. Today we are burning ever-increasing amounts of oil for transportation and coal to generate electricity. The carbon in these fossil fuels has been part of Earth's geosphere for millions of years, in the long-term part of the carbon cycle. By burning carbon-based fuels for energy, we are moving huge amounts of carbon out of the long-term part of the carbon cycle and into the atmosphere as carbon dioxide. The carbon would have remained in the long-term geologic carbon cycle for millions of years if we were not burning it, but it is now entering the atmosphere, altering the former balance between carbon in the short- and long-term parts of the carbon cycle. The increase in the concentration of carbon dioxide in our atmosphere is increasing global temperatures.

Teaching Tip

Just as the water cycle includes places where water is found and processes that move it among those places, the carbon cycle includes reservoirs of carbon and the processes that move carbon among them. For example, as water moves from the ocean into the atmosphere through evaporation and back into the ocean through condensation, carbon can move from the atmosphere into plant sugars through photosynthesis and then back into the atmosphere through combustion (burning). This historical separation of carbon-cycle processes into different disciplines may prevent students from developing a coherent picture of the whole carbon cycle.

Fossil fuels contain carbon that has been trapped for millions of years, such as coal in this coal mine.



The Carbon Budget. Scientists are constantly working to refine their knowledge about the amounts of carbon moving through different parts of the carbon cycle. In Chapter 1, you saw that scientists track energy using a global energy budget, or energy balance. When scientists track carbon, we call this the **carbon budget.** Just as we budget our money by keeping track of the amounts that we deposit and withdraw from our bank accounts, the carbon budget describes the amount of carbon that enters and exits different parts in the carbon cycle. The carbon budget tells us how much carbon is stored in each carbon reservoir and how much carbon is moving between those reservoirs. Accounting for the amounts of carbon in each place and process helps scientists understand the system's balance and predict how it will affect other parts of Earth's system.

The length of time carbon stays within any carbon reservoir varies. For example, the time a single carbon atom remains in a plant may be as little as a

few weeks or months. Yet, carbon atoms found in fossil fuels have been in those reservoirs for millions of years. The carbon budget tells us how much carbon is stored in each of the key carbon reservoirs—the atmosphere, the ocean, the terrestrial biosphere, and the geosphere.

The carbon budget accounts for carbon leaving and entering each of the reservoirs. The processes that move carbon from one reservoir to another are called **carbon fluxes.** Photosynthesis, for example, moves carbon from the atmosphere to the biosphere. Combustion of fossil fuels moves carbon from the geosphere to the atmosphere. By estimating the amount of carbon moving through each flux, scientists try to determine if reservoirs will remain in balance.

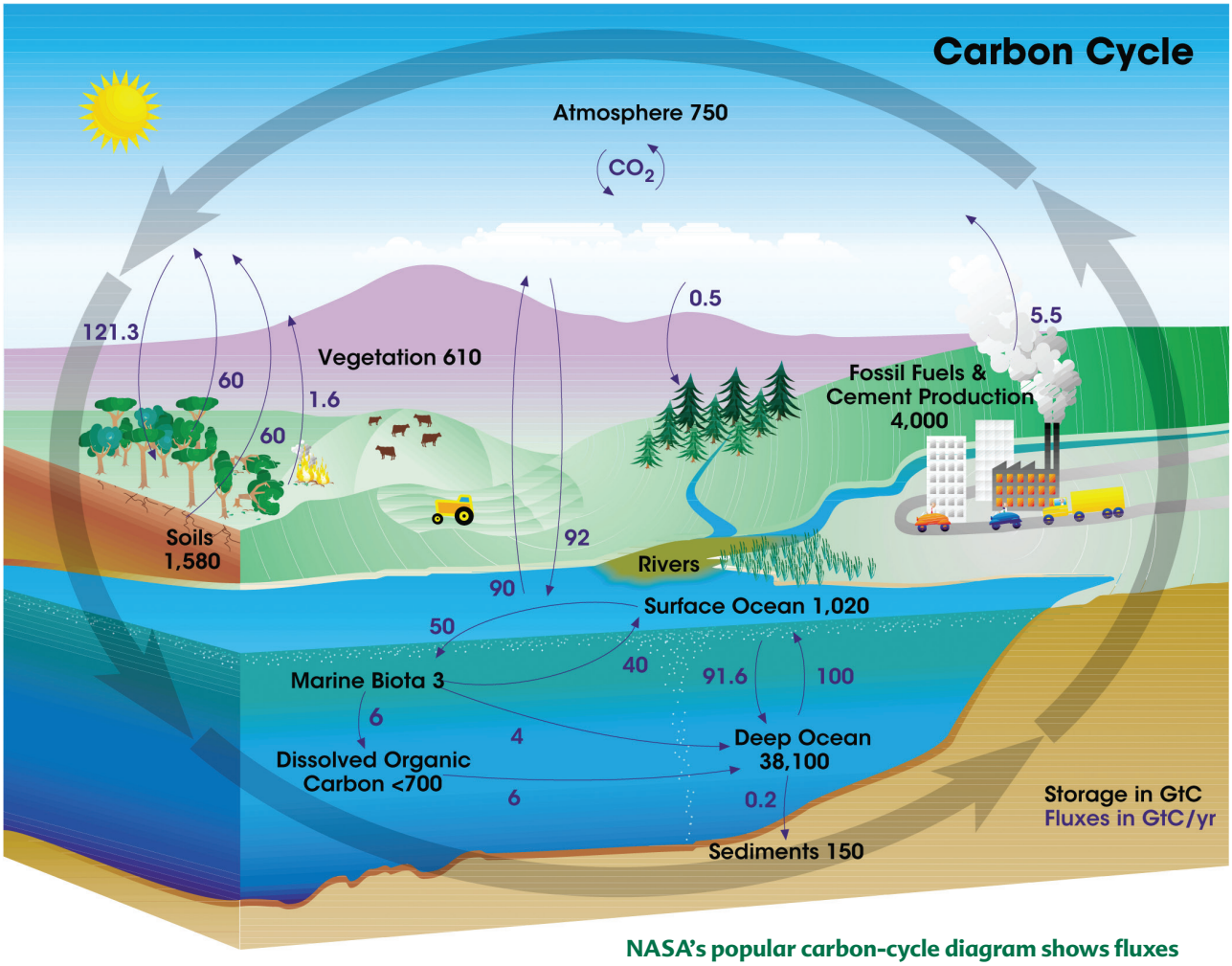
Carbon-cycle diagrams use arrows to show the flow of carbon in or out of reservoirs. Sometimes reservoirs only include one arrow, indicating that it is either a sink or a source. For example, fossil fuels are considered only as a net source of carbon, because it would take millions of years for that reservoir to absorb new carbon.

Some reservoirs take in and give off carbon. For example, vegetation and photosynthesizing organisms in aquatic ecosystems use carbon dioxide for photosynthesis, but they also give off carbon dioxide during respiration. In the long run, plants are a net **carbon sink** because they take in about twice as much carbon as they release.

Carbon-Cycle Processes

The carbon cycle is already included in teaching standards for K–12 education, and its prominence in curricula is likely to grow in coming years. However, the organization of carbon-cycle curricula is currently fragmented across grades and science disciplines. Students may

THE CARBON CYCLE



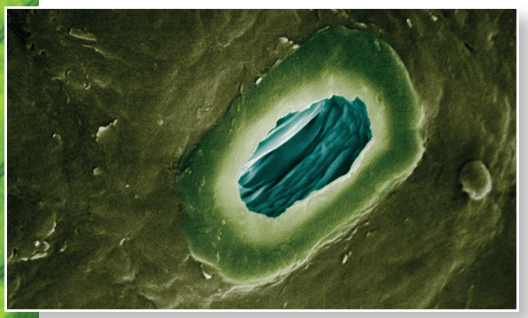
NASA's popular carbon-cycle diagram shows fluxes between carbon reservoirs as well as the movement of carbon within the ocean. Credit: NASA Earth Observatory

learn about photosynthesis in their life science or biology course, read about the carbon cycle in Earth science, and complete experiments on combustion in a physical science or chemistry course. The connections among these processes may not be explicit when students receive this information in separate experiences.

Consider the difficulty students might have with the water cycle if they learned about evaporation at one grade level, but didn't have an opportunity to learn about condensation for another year or two. How complete would students' understanding of water cycling be if they received this type of instruction? Clearly, students need instruction that makes explicit connections among the various processes in the water cycle. Similarly, they need to learn about the full cycle of processes that move carbon so they are not learning about one process here and another process there. Ideally, students should learn about all the processes that move and change carbon in a connected cycle.

Photosynthesis. Photosynthesis is the main process by which organic carbon is generated from atmospheric carbon dioxide in living organisms. Plants, algae, and photosynthesizing bacteria take in carbon dioxide from air and water and use energy from the sun to transform these materials into energy-rich sugar compounds. The leaf of a plant is the primary site for photosynthesis. Chlorophyll, a green pigment found in plant cells, absorbs sunlight and makes it available in the cell. From the raw materials of carbon dioxide, water, and energy, the cells build carbon compounds (sugars) that incorporate the energy from the sun within the chemical bonds.

Photosynthesis is a unique biochemical process. It is the only process known that can harness the sun's energy as chemical energy in biomass. Almost every living organism on Earth depends on the success of this process. ***Primary productivity*** is a term used to describe large-scale conversion of carbon dioxide into organic carbon compounds through photosynthesis.



Plant leaves have openings called stomata to take in gases from the air, including carbon dioxide.

Plants don't incorporate all the carbon dioxide that enters their stomata: More than half of the carbon dioxide that enters the leaf exits unchanged when the stomata open to release gases such as water vapor. The exchange of gases between plants and the atmosphere is called respiration. The same term applies to the process of animals exchanging gases with the atmosphere, but we also know it as breathing. ***Net primary production*** is a term that describes the amount of carbon plants actually incorporate into their structure after taking respiration into account. Net primary production varies widely for different ecosystems. For example, tundra and relatively sparse boreal forests produce carbon compounds, but tropical forests, savannahs, and grasslands can produce around 10 to 20 times as much carbon compounds in the same amount of time. In general, vegetation-rich ecosystems provide greater opportunities for carbon storage.

Transforming Organic Carbon. When carbon compounds move through ecosystems, the compounds change forms at various points along the way. These changes happen through processes such as digestion and biosynthesis, in which incoming carbohydrates, proteins, and lipids are broken down and rearranged into new materials in our cells. Physical growth of our bodies is a visible indicator that some of those materials remain in our body structure. For example, when we eat a hamburger, our bodies do not store the meat and bread in the same form that we ate them. Instead, digestive and metabolic processes in our bodies break the food down into molecular "building blocks," and then reassemble them into new molecules. Some of the new molecules are used immediately through cellular respiration, while other molecules remain in our bodies to help us grow or replace or repair body tissue.

While digestion and biosynthesis are transformation processes within a single organism, food chains and webs show transformation happening at an ecosystem level. We can look at how carbon moves through an ecosystem by examining how it passes from one **trophic level** to the next. A trophic level refers to the place an organism occupies

Student Thinking

Confusion About Plants and Climate

While photosynthesis is commonly taught in American schools beginning as early as third and fourth grade, students continue to show misconceptions well into high school and college. The popular *Private Universe* series shows that even Harvard graduates could not explain where the mass of a plant comes from. This misconception has been well documented in educational research over the last three decades (e.g., Driver, Squires, Rushworth, & Wood-Robinson 1994). Students often do not recognize carbon dioxide as a contributor to plant mass. With plant processes, students may overemphasize plants' production of oxygen, ignoring their important uptake of carbon dioxide.

Scenario

As part of your climate change unit, a local ecologist plans to visit your classroom to emphasize the importance of trees in the health of our planet and atmosphere. Before her visit, you ask your class to share their ideas and questions with the ecologist so that she knows more about what these students think about the topic.

Question

How can cutting down trees be related to climate change?

Scientific Answer

Photosynthesis, including uptake of carbon dioxide, is key to understanding a plant's role as a carbon sink. Plant mass contains a great deal of water, but when looking at the dry mass of a plant, most of this mass comes from carbon that was incorporated into the plant structure during photosynthesis. Through this process, plants are taking the carbon from the CO_2 in order to grow their mass, and releasing the oxygen that was previously part of the CO_2 molecule. In this way, plants are a critical storage reservoir for organic carbon.

Student Answers

Casey: Some people think that it will cause a lack of oxygen that will cause global warming. Cutting down trees can make us lose shade, that will make it hotter.

Dante: Trees take CO_2 out of the atmosphere and replace it with oxygen. Without trees, CO_2 remains in the atmosphere.

Devon: I don't think cutting down trees will increase global warming necessarily, but I do think it will cause problems. Global warming has to do with chemicals being trapped within the ozone layer.

Melinda: The decrease in trees leads to a decrease in the oxygen production from plants. It changes the oxygen levels in the atmosphere, which means there are less gases to shield the sun's harmful rays, letting more heat in causing the temperatures in our climates to rise.

Stephanie: Less plants would be doing photosynthesis and more carbon dioxide would be floating around, which could make the atmosphere hotter.

What Would You Do?

1. You want your students to understand the important role of trees in taking in carbon. What would your instruction look like?
2. What key concepts might you tackle with students prior to the visit from the ecologist?

Pictures of Practice

Trees and Climate Change

As you saw in **Student Thinking: Confusion About Plants and Climate,** understanding the relationship between plants and climate change is a tricky concept for students. Often, students will be able to tell you part of a process, such as carbon dioxide is used by plants for photosynthesis, but many may not be able to identify how cutting down trees will disrupt this process. Students may focus on cutting down trees as impacting other things, such as the availability of clean air or shade for people or homes for wildlife.

Students: Grade 6 and Grade 8

Location: California

Goal of Video: The purpose of watching this video is to see students explain the connection between cutting down trees and climate change.

Classroom Context

The interview clips shown in this video were taken during the spring of the school year after both sets of students learned more about climate change. While students never directly talked about trees and climate in their class lessons, both sets of students learned about the connection between carbon dioxide and climate change. The first part of the video shows sixth-grade students describing the connection to trees and climate. The second half of the video shows eighth-grade students answering the same question. Think about the different types of responses you hear from students in the same grade as well as differences between grade levels.

Video Analysis

A scientific answer to this question would focus on trees and plant life being important carbon sinks, removing large amounts of carbon dioxide from the atmosphere through photosynthesis. At both sixth grade and eighth grade, students should know that plants take in carbon dioxide, and a good answer to this question would mention carbon dioxide taken in through photosynthesis. In this video, sixth graders—Emily, Samantha, and Eliazar—make the connection between trees and climate change using carbon dioxide. They know that trees take in carbon dioxide and give off oxygen. Because these students have an understanding about carbon dioxide being used by plants, this becomes a potential leveraging point for their teacher. However, when these students are asked about trees being cut down, they describe carbon dioxide being "released" as opposed to explaining that plants can no longer take in carbon dioxide. Next, the eighth-grade students—Burhon, Marc, Hailey, Xena, and Ian—give more diverse explanations. Marc says he doesn't know how cutting down trees is related to climate change, while Ian provides the most sophisticated answer of the group—that the trees can no longer uptake carbon dioxide.

Reflect

How could you help students connect trees to climate change?

The sixth-grade students seem to understand that trees take in carbon dioxide but have trouble explaining the link between cutting down trees and increased carbon dioxide. Given this pattern, how would you plan instruction to make this connection more developed among students? For the eighth-grade students, the understanding of how trees are connected varied greatly. Given that all five students are in the same class, how would you handle this diversity as you teach the topic?

Food chains show how materials and energy are passed from organism to organism.

in a food chain. The lowest trophic level consists of plants and other producers that gather energy from the sun. The trophic level increases as energy moves up the food chain—first to herbivores, or plant eaters, and then to carnivores, or animal eaters. Carbon enters the ecosystem through photosynthesis and is transformed into sugars inside plants or producers. Once these plant products are eaten by a primary consumer (e.g., a rabbit), the carbon may be digested and stored inside that animal's body. If the primary consumer is eaten by a secondary consumer (e.g., a wolf), the carbon compounds are broken down again and rearranged and stored inside the body of the secondary consumer. In this way, some carbon makes its way through several organisms and trophic levels before it is returned to the atmosphere through respiration.

Fossil fuel formation is another example of the transformation of carbon. Plants and animals from millions of years ago took in carbon compounds and stored them within their structure. After these ancient plants and animals died and were covered by sediments, pressure and heat changed the materials into the hydrocarbons that comprise fossil fuels. The carbon remained in an organic form throughout this process.

Three workers caked in oil turn piping to plug a well in Alberta, Canada.

Oxidation of Organic Carbon. Carbon compounds, such as food or fuels, are rich with chemical energy. When these compounds react with oxygen in a process called oxidation, chemical energy is released as heat. Oxidation processes include cellular respiration in living organisms, decomposition (rotting) of formerly living things, and combustion, also known as burning. As oxygen reacts with carbon compounds in these processes, carbon dioxide is always one of the byproducts.

Oxidation processes are key to understanding where our carbon dioxide is coming from. Respiration from animals release carbon dioxide into the atmosphere. Additional carbon dioxide is released from soil as microbes break down organic matter contained within it. Deforestation and other

Student Thinking

Transformation of Carbon

Students can struggle with understanding transformation processes. While most students know that some of the food we eat stays in our bodies, they do not always understand this process as the break down and reassembly of the same atoms that entered their bodies. Food chains are usually presented as a step-by-step story of "who eats who." However, students are rarely asked to trace the materials flowing through a food chain. The following chart compares student conceptions about digestion, growth, and food chains, to science concepts that students are expected to learn in school.

	Common Student Conception	Science Concept
Digestion	Food is eaten, goes through the digestive system and is turned into energy for our bodies or expelled.	Food is eaten, and the materials are broken down into atoms and molecules that are transported to cells and reassembled into molecules the body can use.
Growth	Living things grow because of all the things they eat and drink over time. This is just a natural process in living things.	Living things grow because they use materials they take in from their surroundings and reassemble them into molecules that add to biological structures.
Food chains	One thing eats another thing, creating a story about who eats who.	Living things obtain energy-rich materials by eating other living things. Some of those materials are used, while others remain in the organism until it is eaten by something else and passed on to the new organism.
Biomass	The largest animals in an ecosystem weigh the most, and therefore, most of the biomass is found in these animals	Biomass decreases as you move up trophic levels. Producers and primary consumers constitute more biomass in an ecosystem than higher-order consumers.

Ask Your Students

1. What happens when you eat food? How do plants and animals grow?
2. What does a food chain illustrate?
3. Which animals have more biomass, producers or consumers?

changes to the way we use land increases carbon dioxide as well.

In comparison to the rate at which natural processes release carbon dioxide into the atmosphere, our burning of fossil fuels seems relatively small. Estimates indicate that the burning of fossil fuels currently adds only about 10 percent as much carbon dioxide to the atmosphere as natural processes do. However, this seemingly small amount of carbon dioxide is being transferred from long-term geological reservoirs into the short-term biochemical carbon cycle. Because carbon sinks at Earth's surface are insufficient to absorb the additional carbon dioxide produced by human-controlled oxidation of fossil fuels, it is accumulating in the atmosphere.

When we eat food, burn fossil fuels, or change the way we use our land, we are making choices about the location of carbon on Earth. Our bodies need to obtain the chemical energy stored in carbon compounds for survival. We use that energy to move and function. We also need power to run our homes and support our lifestyles. In our quest for this energy, we oxidize large amounts of organic carbon compounds, producing carbon dioxide as a byproduct.

In this chapter we explored how carbon moves through Earth's separate spheres and discussed challenges that teachers face in helping their students to make connections between separate processes within the carbon cycle. We highlighted the difference between the long-term parts of the carbon cycle and the short-term parts and pointed out that many pieces of the cycle are taught in different grades and courses within a school's science curriculum. We also introduced the idea that food and fuel must be oxidized to release its chemical energy, and the products of this oxidation reaction are energy, carbon dioxide, and water. In the next chapter, we will take a closer look at how our needs for energy have changed over time, as well as the places where we can get it.

Teaching Tip

Start with students' everyday experiences of eating and breathing to help students make connections between the reactants and products of oxidation processes. Most students know that they take in food and oxygen and expel carbon dioxide. Just as burning coal in a power plant or gasoline in a car's engine requires oxygen, our bodies require oxygen to "burn" our food. Another way of stating this is that the compounds in food need to be oxidized for the body to obtain the energy they contain. The products we give off through respiration as a result of reacting oxygen with carbon compounds are carbon dioxide and water.

Our bodies oxidize food to obtain energy to function. Our cars oxidize gasoline to obtain energy. How are these process similar and different?

Student Thinking

Burning Gasoline

When students are asked to explain where matter goes during reactions in which it seems to disappear, they often invoke solid-solid or solid-liquid conversions instead of explaining the change of solids-liquids to gases. Students often invoke solid-liquid conversion to explain where the matter of a candle goes as it burns. Students describe the candle melting, but they may not grasp that the wax is being oxidized and transformed into gases that enter the air.

Scenario

Your students have just discussed what happens to propane in a barbeque grill and what happens to a candle as the wax burns. You are about to start an activity on gasoline in cars but want to assess how much your students will already know about this topic. You have your students free write in their journal about the following questions, and then share as a whole group.

Question

Where does the gasoline go as it is used by a car? Is burning gasoline related to climate change?

Scientific Answer

An internal combustion engine uses gasoline by causing it to react with oxygen. Gasoline is mixed with air, compressed by a piston, and then ignited by a spark plug. The resulting explosion pushes the piston, which turns the crankshaft and drives the wheels, moving the car. Exhaust from the explosion leaves the engine through the tailpipe. The exhaust contains carbon dioxide and water vapor, but it also contains carbon monoxide, nitrogen dioxide, and sulfur dioxide, which contribute to climate change and air pollution.

Student Answers

Karin: All of the gas is sucked into the engine. The engine needs a combustible liquid or gas to push the pistons. The matter of gasoline turns into CO_2 (carbon dioxide). Too much CO_2 in the air can create a thicker layer of atmosphere, and when the sun's rays can't escape, the rays heat up the atmosphere.

Maria: The gas has been worn out and became energy. The gasoline produced smoke, which ruins the ecosystem and the ozone. Then the UV rays come in quicker.

Darian: I think the gas is burned, and it evaporates into the air. Those gases are bad for the air and make the air hotter and glaciers melt.

Jessie: It goes into the air. I don't think it's related to climate change.

What Would You Do?

1. From the answers given, you decide Karin is starting off with a better-than-average understanding but that most students are not transferring what they already learned from the prior discussions of the candle and propane. Of the ideas mentioned, which concepts would you focus on teaching during your lessons on combustion in cars?
2. How would you address incorrect ideas about the topic through your instruction?

Pictures of Practice

Combustion and Carbon Dioxide

Most students gain some experience with fire and burning from an early age. They have watched flames consume wood and other fuels, giving off smoke and leaving behind ashes or other products after the flames have gone out. Smoke and ash are the visible products of burning, so students use these as a way to trace where materials go when they burn. Understanding how gasoline burns in a car's engine can be even more difficult for students because the actual combustion process is hidden from sight. Another potentially confusing factor is that the fuel is a liquid rather than a solid, such as wood. As gasoline is pumped into a hidden reservoir in the car, and the tank eventually becomes empty and has to be filled again, most students have no visual cues about what happens to the gas. Students may know the car is burning a fuel, but their explanations reflect misunderstandings about how this process happens inside the car, and what products are given off when gasoline burns.

Students: Grade 6

Location: San Marcos, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss their ideas about how fuels change inside a car.

Classroom Context

Previously, Ms. Walker had taught her students about combustion, using the analogy about the food we eat. Students discussed how the food we eat is like the fuel we put into our cars. Ms. Walker hoped that her students would see similarities in the two processes and liken our exhaling carbon dioxide to carbon dioxide given off by cars.

Video Analysis

Car engines are complicated, even to adults, but on the most basic level, the gasoline we put into our car does not evaporate like water or turn into energy, but rather it is oxidized in the car engine and gives off carbon dioxide, water, and other chemicals as exhaust. In this video, you will see Ms. Walker and her students talking about what happens to gasoline in cars. Many students quickly develop the idea that the gasoline turns into a gas that goes into the air, but they give interesting explanations about how this happens during their post interviews. For example, Alan describes gasoline as being burned by the motor, but he has a hard time explaining what he means by burning. Eliazar describes the carbon dioxide as the same thing as energy. Finally, Emily describes gasoline turning into "kind of like a gas" and states "if you keep it (carbon dioxide) in your car, it will mess up the engine, so they release it out."

Reflect

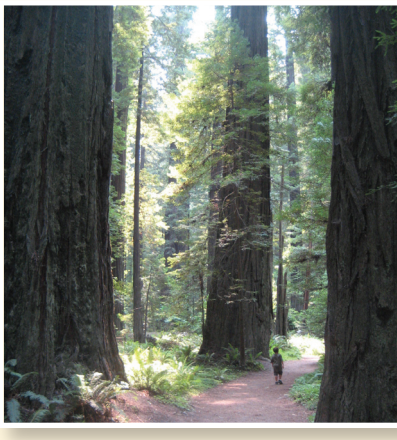
How would you teach about burning gasoline in cars?

As you listen to the post-interview explanations, think about not only what students had learned in class, but also about the areas in which they are still confused or could improve their understanding. How would you deal with Eliazar's confusion between carbon and energy? How would you structure your lessons about combustion in car engines given the concepts students easily learn versus the concepts they misunderstand?

In the Classroom

California Land Use

Since Europeans settled in California, land use and management has drastically changed the natural environment. Human use of the land for ranching, agriculture, and urban development have reduced the state's ecosystems capacity to store carbon. One way to connect the carbon cycle to your students' daily experience is to draw connections between the cycle and the way we use our local lands.



Have students look at the National Geographic/EEI People and the Environment map (see following page). Consider how the changes in land use have influenced the carbon cycle in California. Have changes increased or decreased the land's ability to store solid carbon? How have human practices changed the carbon cycle around their homes and in their communities?

Redwood Forests. Redwood trees can reach 350 or more feet in height and store incredible amounts of carbon. Today, only a small percentage of the original redwood trees in California remain standing. Discuss how deforestation and reforestation alter the amounts of carbon in different parts of the carbon cycle.

Forest Fires. Engage students in a discussion about how forest fires move carbon through its cycle. Burning (oxidizing) wood changes organic carbon compounds stored in trees' trunks and leaves into carbon dioxide. After a forest burns, new plants will eventually begin to grow there again. Over time, a new ecosystem will gradually develop new vegetation and regain the ability to absorb carbon again.

Urban Development. Using the People and the Environment map, have students determine how much land has been developed into cities during the last two centuries. Have students explain how urban development altered the amount of carbon in different parts of the carbon cycle in California.

Agriculture. Much of California's land is used for ranches and farms. As a result, the state produces more agricultural products than any other state in the United States. Have students discuss how farms alter the amount of carbon in different parts of the carbon cycle, especially in areas that were once forests or grasslands. With older students, discuss how the effects of agricultural practices affect soil respiration and the amount of carbon released from fields where crops are grown.

California
Education and the Environment Initiative

People and the Environment

GARY CRABBE / ALAMY

MARK & AUDREY GIBSON

JOHN LAWLOR / ALAMY

BLOCKWHEEL / ALAMY

JARED LUDWIG / CORBIS

KEVIN PANIZZA / ISTOCKPHOTO

JAMES D. WATT / IMAGE QUEST MARINE

JOSEPH SOHM/VISIONS OF AMERICA / CORBIS

Representations of Science

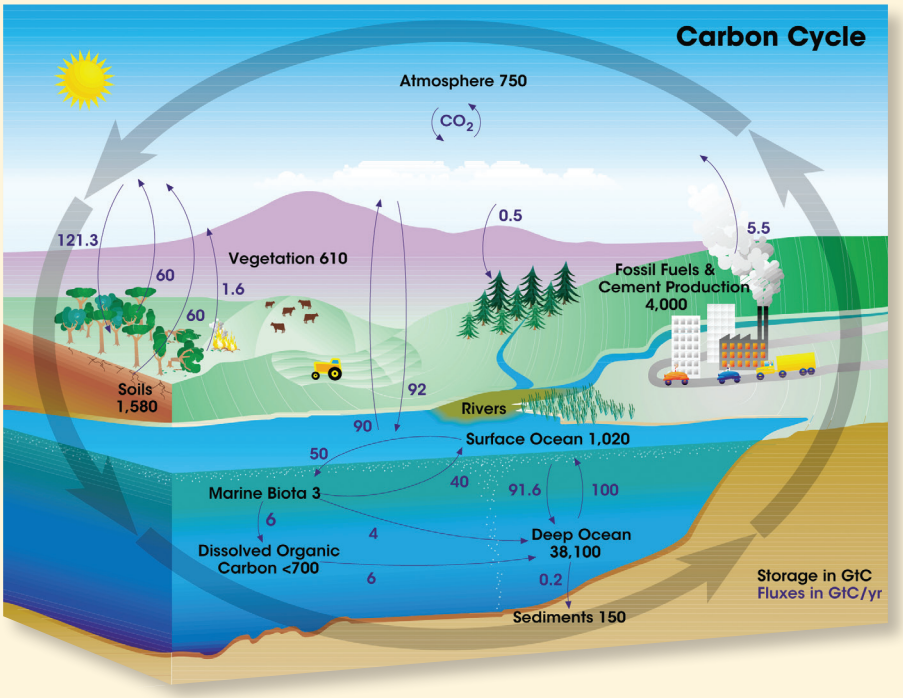
Using Carbon-Cycle Diagrams

Carbon-cycle diagrams play an important role in helping students visualize carbon reservoirs and the processes that move carbon between them. They can also serve as a guide to help students develop a coherent story about the carbon cycle.

Different carbon-cycle diagrams offer particular features that speak to certain ages of students, but those features also impose limitations. For example, any time a diagram is used to represent a process or other information, an additional step of interpretation is introduced to the learning sequence. Learners may need support to make sense of what the features of the diagram represent. For instance, they may need instruction to interpret what is described by an arrow, icon, or numerical value. Additionally, when depicting a complex system such as the carbon cycle, learners can benefit from instruction about information that has been omitted or exaggerated. Interpreting graphics or diagrams in a discussion before asking students to use them for analysis can help you to identify potential misconceptions or concepts that students may struggle with as they use the representation. Following we examine three styles of carbon-cycle diagrams and note the benefits and trade-offs of each.

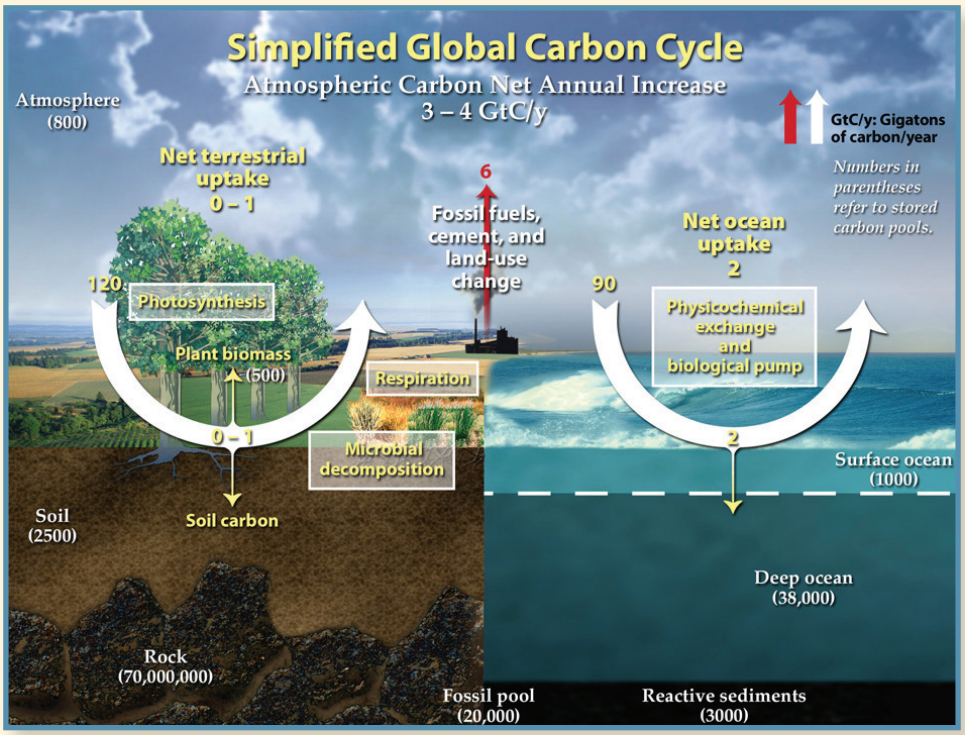
Traditional Carbon-Cycle Diagram

NASA's carbon-cycle diagram is a traditional representation of the carbon cycle that includes major carbon sinks and key fluxes. The diagram includes a simple key and mostly whole numbers with very little notation. There is also a circular arrow that surrounds the illustration indicating that carbon flows in a cyclical path. By covering up particular parts of the diagram, a teacher could walk students through the process that each arrow represents before expanding the view to include the whole system. However, the arrows in the diagram do not help students identify key carbon-cycle processes, without assistance from a teacher. The complexity of the diagram may also cause some confusion among students. One way to reduce the amount of information is to use similar diagrams that do not contain carbon flux numbers. In this way, a teacher can focus on what each arrow means, without going into the quantity of carbon moving with the arrow. However, if a teacher wants to address quantity, these numerical values are critical.



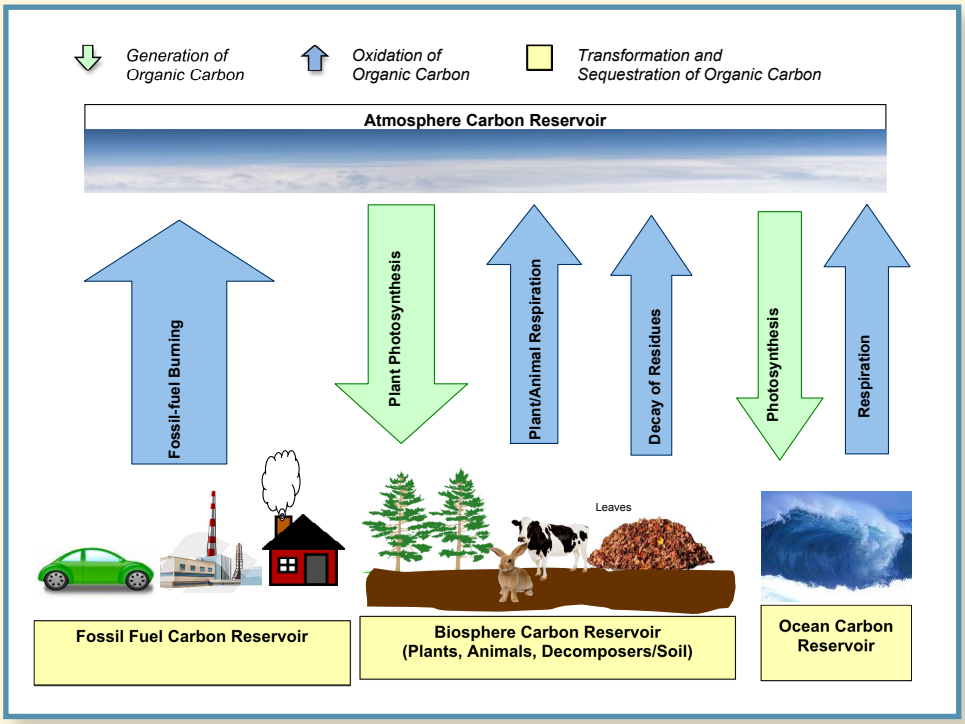
Marine Versus Terrestrial Representation

The representation produced by the U.S. Department of Energy has separated the terrestrial carbon cycle from the ocean carbon cycle, allowing for an in-depth look at each system and comparison between the two. The separation, however, may lead students to think that carbon cannot move freely between these two systems. In fact, carbon is not confined within one system or the other. In fact, the ocean is a major uptake of the extra carbon dioxide emitted from terrestrial ecosystems.



Tracing Carbon-Dioxide Diagrams

The Environmental Literacy Project at Michigan State University produced a representation of the carbon cycle that highlights processes that move carbon dioxide into and out of the atmosphere. The benefits of such a diagram are that it simplifies the system by focusing on carbon-dioxide movement and by drawing attention to carbon cycling processes. However, the width of the arrows and size of the boxes do not accurately represent the relative magnitude of each reservoir and flux. This could lead to misunderstandings about the amount of carbon stored in each reservoir and movement via the processes represented by each arrow.



Each diagram depicts the movement of carbon through Earth's carbon reservoirs in a different manner. Which diagram seems most suitable for your students? Why? As you choose representations to use with your students, consider the trade-offs of each and how the representation is going to help you achieve your goal for student learning.

Resources

Driver, Rosalind, Ann Squires, Peter Rushworth, and Valierie Wood-Robinson. *Making Sense of Secondary Science: Research into Children's Ideas.* London: Routledge, 1994.

Mohan, Lindsey, Jing Chen, and Charles W. Anderson. "Developing a multi-year K–12 learning progression for carbon cycling in socio-ecological systems." *Journal of Research in Science Teaching* 46. 6 (2009): 675–698.

The Carbon Cycle. NASA Earth Observatory. 2010. http://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-carbon-cycle/. May 3, 2010.

Simplified Global Carbon Cycle. U.S. Department of Energy. 2009. https://public.ornl.gov/site/gallery/originals/Pg002_CCycle08.jpg. May 3, 2010.

Teaching Resources

California Education and the Environment Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm

Environmental Literacy Project carbon materials: http://edr1.educ.msu.edu/EnvironmentalLit/publicsite/html/carbon.html

NOAA/ESRL Carbon Cycle Toolkit: http://www.esrl.noaa.gov/gmd/education/carbon_toolkit/basics.html

What is a Carbon Cycle Activity: http://www.ucar.edu/learn/1_4_2_15t.htm

3 Energy to Power Our World

by Nicole D. LaDue and Lindsey Mohan

Before the discovery of **fossil fuels,** our ancestors relied primarily upon wood and other plant materials for fuel. Every day, people had to collect enough burnable material for cooking, heating homes, and fueling fires to make tools. In developing countries, some populations still live this way. Since the 1800s, however, industrialized nations have greatly developed the capacity of fossil fuels to provide power for many human activities.

Today, industrialized nations use carbon-based fossil fuels such as coal and petroleum for heat and power. These fuels make our way of life possible. We use gasoline to drive to work and school, and much of the electricity we use to run our homes and businesses comes from burning coal or natural gas. We also use petroleum fuel to ship goods around our nation and the globe. Other fuel sources, such as nuclear, hydroelectric, wind, and solar provide energy to our electricity grid, but most of our energy comes from burning fossil fuels.

In this chapter, we will discuss how our energy use has changed over time, especially since the Industrial Revolution. We will take a closer look at how fossil fuels form in order to understand what makes these materials so energy-rich and discuss how the burning of these fuels has contributed to anthropogenic (human-caused) climate change. Finally, we'll examine scientific data on carbon dioxide emissions from different activities we engage in everyday.

Energy Portfolios

An **energy portfolio** describes the types and amounts of energy used by a society. A well-developed and desirable energy portfolio is often described as a diverse portfolio. Centuries ago, people did not have many options for fuel, so energy portfolios were not diverse. They likely consisted of wood or other plant and animal-based products, such as charcoal. Wind energy from windmills was harnessed by some societies. In the mid-1800s, as humans started to use coal and water power to run newly invented machines, energy portfolios

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.2 3.5.1-3	The Geography of Where We Live California's Economy—Natural Choices
Grade 4	4.1.5	Reflections of Where We Live
Grade 5		
Grade 6	6.3.b 6.6.a-c	Energy: It's Not All the Same to You! Energy and Material Resources: Renewable or Not? Made from Earth
Grade 7		
Grade 8	8.6.1 8.12.1 8.12.5	Agricultural and Instustrial Development in the United States Industrialization, Urbanization, and the Conservation Movement

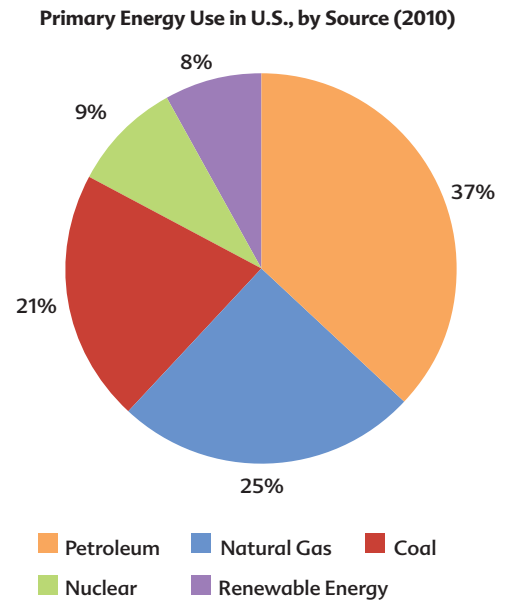
became more diverse. Today, our energy portfolios are even more diverse, using both fossil fuels and alternative energy sources, such as nuclear, solar, or wind energy.

Energy portfolios are represented in a variety of ways, but oftentimes we see these portfolios as pie charts with percentages showing different energy sources.

Energy in the United States

Energy usage in the United States has changed dramatically over its relatively short history. Before the 1850s, most of

EXAMPLE ENERGY PORTFOLIO



The example energy portfolio presented here shows a portfolio for an industrialized country today. This portfolio shows that the only 8 percent of the energy used in the United States comes from renewable sources.

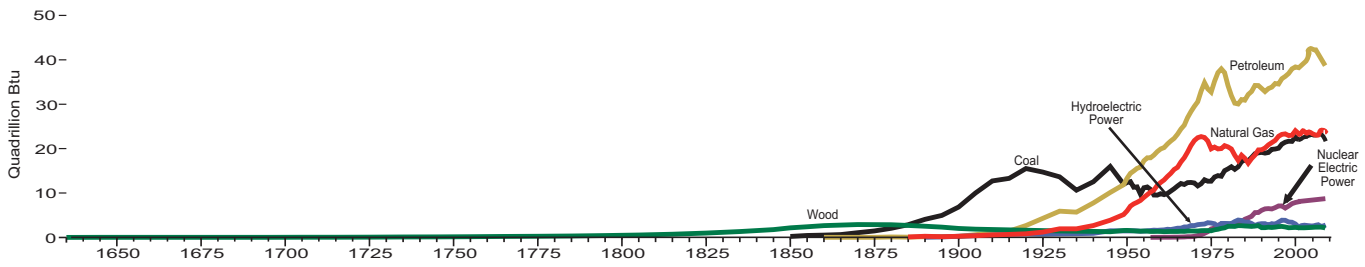
CHAPTER OVERVIEW

The technology we have today requires a great deal of energy to keep our societies functioning. Most of this energy comes from fossil fuels, whereas just a few centuries ago, this energy came primarily from wood and other plant-based materials. Today, our energy needs are met mostly with fossil fuels we extract from deep underground, but we also use other sources of energy by harnessing wind, solar, hydroelectric, and nuclear power, to name only a few.

Energy portfolios are a way societies represent their energy sources. Some countries have more diverse portfolios compared to other countries. Energy use in the United States relies predominantly on fossil fuels, but use of these fuels is different. For example, coal and natural gas are primarily used to power homes, while petroleum is used for transportation. The use of fossil fuels in the United States and Canada dwarfs use by other industrialized nations. Fossil fuels are ancient plant-and-animal materials buried millions of years ago and, through time and pressure, transformed into the energy-rich hydrocarbons we burn today.

The chapter explores how energy needs have been met over time and takes a closer look at the discovery and use of fossil fuels in modern times.

U.S. ENERGY OVER TIME



Energy use in the United States has grown dramatically since the 19th century. Today, energy resources are more diverse, but Americans still rely mostly on fossil fuels to meet energy needs.

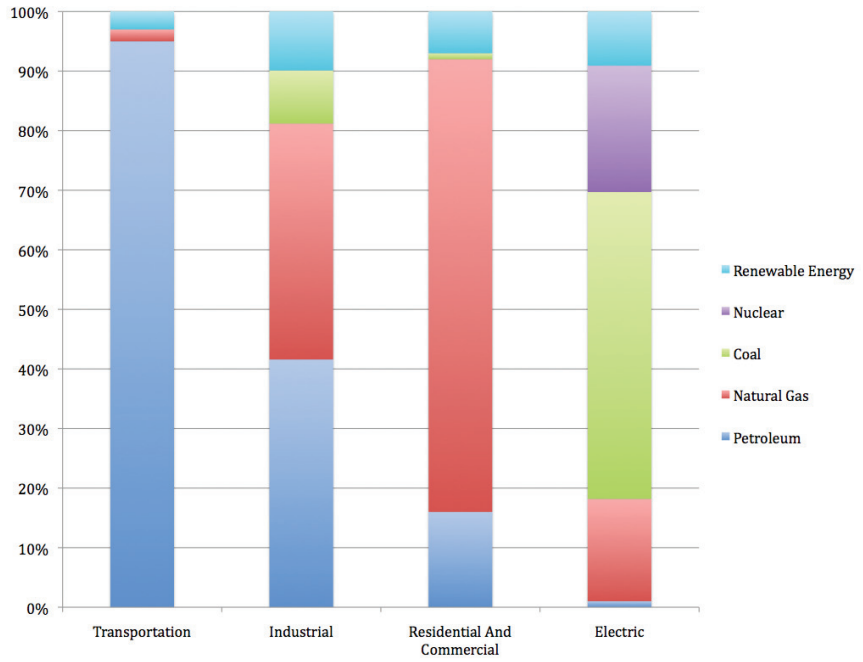
the forest east of the Mississippi River was cleared as humans used the trees for energy and building materials. The energy we use today comes from a more diverse mix, including fossil fuels, nuclear power, and renewable energy sources such as biofuels and wood products, plus hydroelectric, solar, and wind power.

Around 1890, coal surpassed wood as the dominant source of fuel in the United States. Despite some fluctuations in the early half of the 20th century, coal use has grown fairly steadily since about 1960. Today, petroleum is our dominant fuel source, followed by natural gas and coal. Alternative energies such as nuclear and hydroelectric power supply just a fraction of the total energy used in the United States.

Energy sources are valued for their energy output. The **British thermal unit (Btu)** is one measure of energy output. A Btu is the amount of energy required to heat one pound of water one degree Fahrenheit. This is about the amount of energy released when burning a match. The energy content of various fuel sources is usually described by Btus. We also use this unit of measurement to describe the capacity of appliances to heat or cool. For example, furnaces and barbeque grills usually indicate their capacity with a Btu rating. The reason that some fuels are highly valued and used more than other fuels is often due to the energy output we can obtain from those fuels. Fossil fuels, for example, provide a great deal of energy compared to other sources such as solar energy.

Currently, we burn fossil fuels to produce more than 85 percent of the total energy used in the United States. Of our total energy use, however, different sources supply different uses. For instance, of all the energy used to power transportation in the United States, 95 percent of it comes from petroleum. Just more than half

ENERGY USE BY SECTOR



In the United States we use our energy resources in different ways. Coal is used to produce electricity for homes and businesses. Natural gas is used predominantly in homes, while petroleum dominates the transportation sector.

(51percent) of the electricity used by appliances in homes and businesses comes from burning coal.

Energy Use Around the World

The United States uses approximately 21.1 percent of global energy consumed each year (Annual Energy Review, EIA 2006). Considering that the country has only 4.6 percent of the world's population, Americans consume, on average, more than any other country, except Canada.

Consider how much energy Americans use by comparing the United States to China. Both countries have about the same land area and use approximately the same amount of energy, but China's population is four times that of the United States. Also, we might think that American lifestyles are similar to those of Europeans, but people who live in the United States use almost twice as much energy per person as people living in Germany, France, or the United Kingdom.

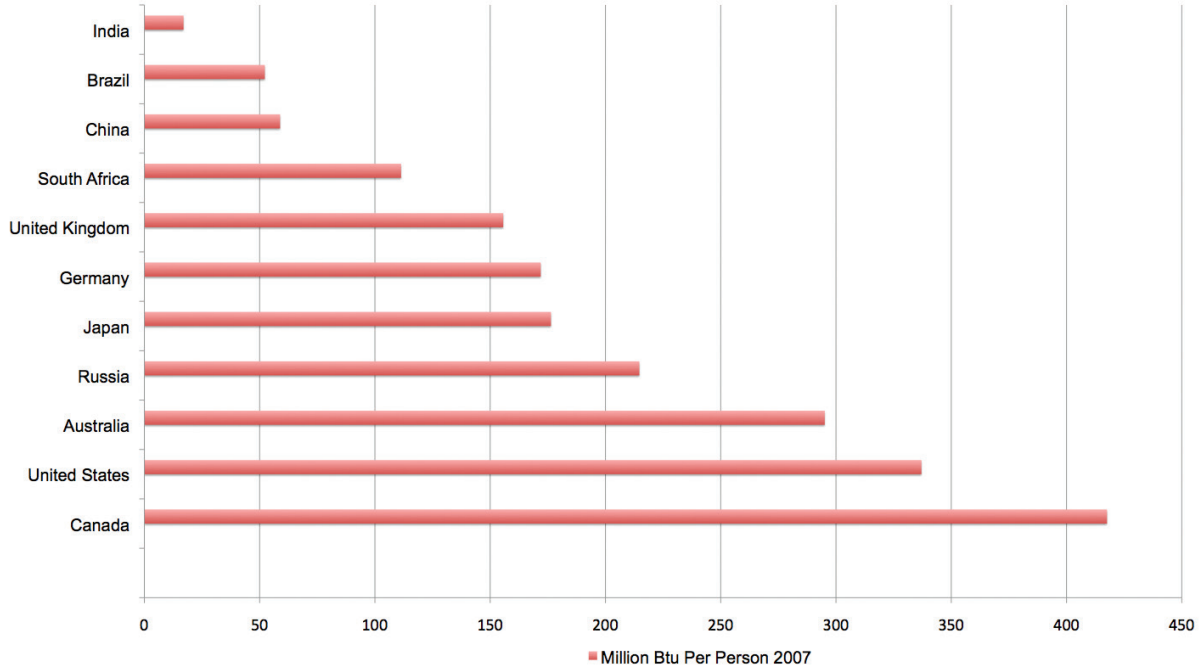
City lights of Toronto, Canada, shine brightly in the night.

Fossil Fuels

Most students have likely heard the term *fossil fuel* in some capacity or another. They may know that we use fossil fuels in our cars, and they might associate these fuels with factories or power plants. Given the high level of attention that climate change and fossil fuels have had in the media, even early elementary students may have some knowledge about fossil fuels.

However, few students have any real idea how dependent their everyday experiences are on the use of fossil fuels. Even if students can name some fossil fuels and know that they come

ENERGY USE PER CAPITA



The U.S. Energy Information Administration (EIA) monitors national and global energy use. In 2007, EIA calculated that American citizens consumed an average of 337 million Btu compared 172 Btu per German citizen and 156 Btu per British citizen. Data can be downloaded from EIA's International Energy Statistics website: http://www.eia.doe.gov/emeu/international/contents.html

from the days of dinosaurs, they are not likely to know what makes them such ideal energy sources, or how they revolutionized our energy system.

What Are Fossil Fuels? Coal, natural gas, and crude oil (the raw material from which gasoline and other petroleum products are derived) form from organic material that has been buried and compacted by natural Earth processes over millions of years. Fossil fuels were once plant and animal materials, but chemical reactions that take place under heat and pressure transformed them into different substances. At an atomic level, all fossil fuels contain hydrogen and carbon atoms that are bonded together into molecules called **hydrocarbons.** The history of heat and pressure changes on the original organic material and the way the carbon and hydrogen atoms are bonded together is different for coal, oil, and natural gas.

Natural Gas. The most common type of natural gas is methane, which has a chemical formula of CH_4. When methane and oxygen gases are together, a small amount of energy (such as a spark) can start a chemical reaction between the two substances. This reaction is known as *combustion,* or burning. In the combustion of a hydrocarbon such as methane, the bonds between carbon and hydrogen atoms break apart to form new bonds with the oxygen atoms. The formation of new chemical bonds with oxygen releases energy—the same amount of energy that it took to bond hydrogen and carbon together through photosynthesis when the plant material was alive. The formation of new carbon-oxygen bonds and hydrogen-oxygen bonds releases more energy than it takes to break the original carbon-hydrogen bonds, so overall, the combustion reaction releases energy.

The chemical equation for the combustion of methane is $CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$ (+ energy). This means that for each methane molecule that chemically combines with two oxygen molecules in a combustion reaction, two molecules of water and one molecule of carbon dioxide plus a specific amount of energy will be produced. Thus, carbon dioxide is one of the products of burning methane. Similarly, other types of natural gas also result in the production of carbon dioxide.

Natural gas plant in Texas

Oil. Crude oil is a combination of liquid hydrocarbon molecules that can be separated into products such

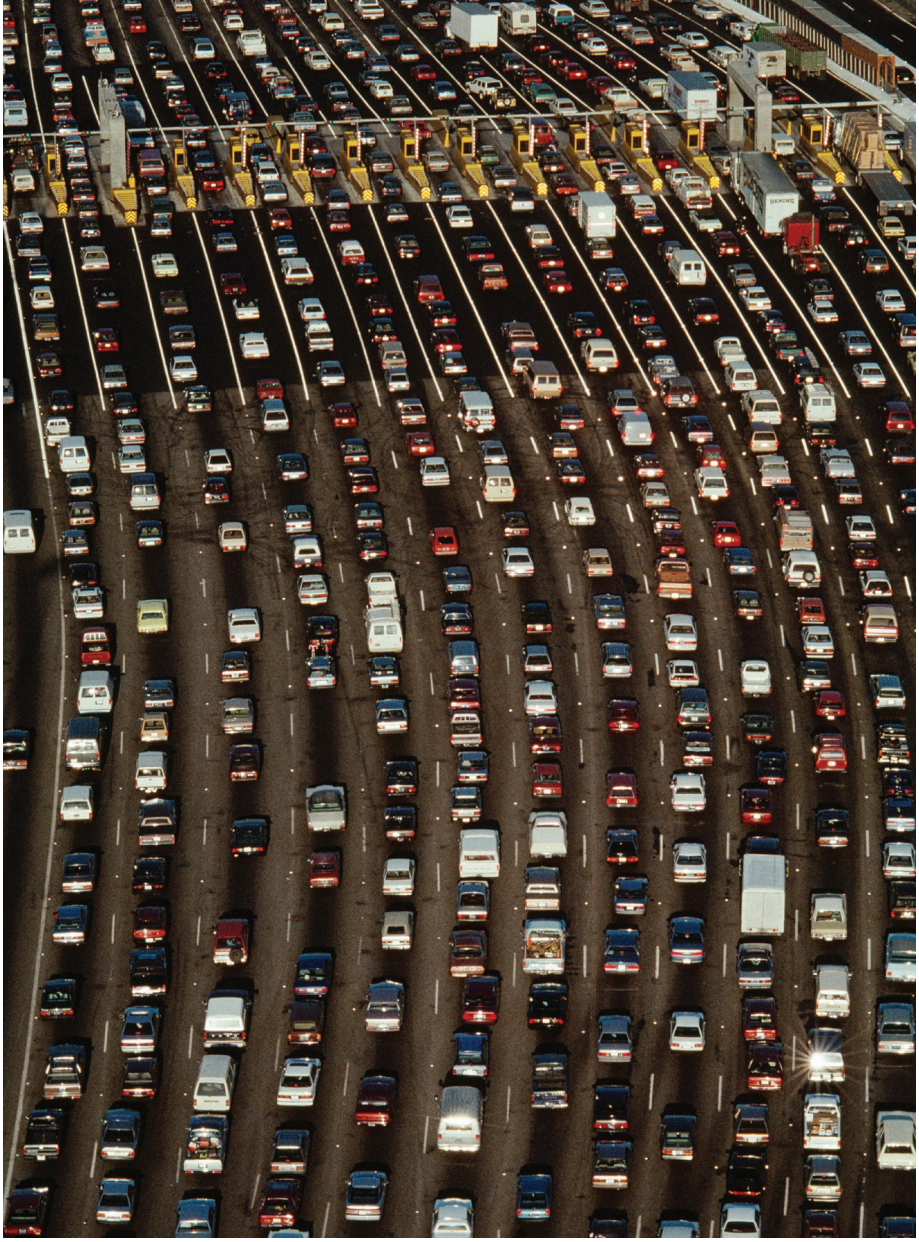
Offshore oil platform in the Gulf of Mexico

as gasoline, heating oil, and asphalt. To separate the black crude oil into its component parts, petroleum refineries raise the temperature of the mixture and capture the products that boil out of it at different temperature ranges. As the temperature is raised, increasingly larger molecules boil out of the mixture and then condense; they can be collected with other similarly sized molecules.

The molecules in gasoline are typically hydrocarbon chains with 4 to 12 carbon atoms per molecule; diesel fuel contains hydrocarbon chains with about 8 to 21 carbon atoms per molecule. When these petroleum products are combusted inside the engine of a car or truck, they produce energy and a molecule of carbon dioxide for every carbon atom involved in the reaction.

Coal. Coal is made mostly of carbon, but it also contains varying amounts of hydrogen, oxygen, nitrogen, sulfur, and other elements. Coal is solid because its carbon atoms are bonded together into strong ring–shaped molecules rather than existing as the hydrocarbon chains found in liquid oil. Coal is classified by the amount of carbon it contains. Coal that has the highest amount of carbon, typically more than 90 percent of the total weight, has the highest potential for producing energy through combustion; this high-grade coal is called **anthracite.** Grades of coal that have progressively lower amounts of carbon are called **bituminous** coal, lignite, and peat. When coal is burned to release energy, the reaction releases carbon dioxide. Burning coal also releases pollutants such as sulfur dioxide, nitrogen oxide, particulates, and mercury compounds. Coal is considered the "dirtiest" fossil fuel for the environment.

How Do Fossil Fuels Form? Fossil fuels have the name *fossil* because they form from the remains of plants and animals that were once alive.



Cars line up at tollbooths during rush hour on the San Francisco-Oakland Bay Bridge.

Though many people associate the term *fossil* only with solid bones or shells, it also refers to any remnants or traces of once-living material.

In general, fossil-fuel deposits represent regions that had abundant life, with swamps and shallow seas dominating the landscape. Over millions of years, natural geologic processes covered these areas with layers of mud and sand. The decaying organic matter was buried and compacted, eventually forming coal, oil, and natural gas.

All fossil fuels represent energy that was originally captured from the sun through photosynthesis. Plants use water, energy, and carbon dioxide to make sugar, converting the solar energy to chemical energy.

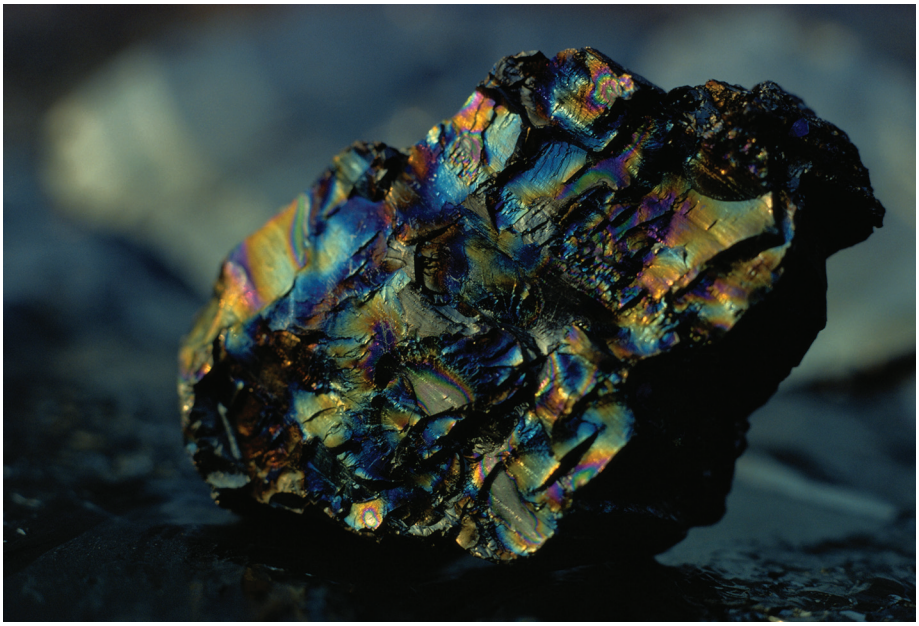
If a plant is exposed to air after it dies, oxygen reacts with sugars in the plant matter, breaking the bonds between carbon atoms. Aided by a variety of bacteria and fungi that ingest and digest the sugars, the plant eventually decomposes. However, if dead plant material is buried under layers of mud at the bottom of a swamp, no oxygen or decomposers can reach the decaying plant matter. In this case, the organic material will not decompose completely, and the carbon it contains is preserved. If additional layers of mud and rocks eventually cover the buried organic matter, the weight can squeeze out any water left in the material. Pressure,

Coal is the most abundant fossil fuel in the United States, and coal mining has been an influential industry for more than a century.

heat, and the absence of water can result in plant sugars ($C_6H_{12}O_6$) slowly transforming into hydrocarbons as the relatively unstable oxygen atoms are removed through slow chemical reactions.

Coal generally forms from buried plant material that grew in swamps and bogs on land. Conversely, deposits of oil and natural gas are formed from the remains of microscopic marine organisms. Small life forms, such as algae and plankton, thrive in shallow ocean waters where they can capture sunlight through photosynthesis or ingest other plankton. When these microscopic organisms die, they fall to the sea floor, taking the carbon-hydrogen-oxygen compounds they built with the sun's energy with them. Great accumulations of these dead organisms can eventually be buried and squeezed by thick layers of sand and rocks. Given the right conditions of heat and pressure over millions of years, the organic material is transformed into liquid oil. Because it is less dense than rocks and water, the oil moves generally upward through **permeable** layers of rocks, such as sandstone, until it is trapped by an **impermeable** layer of rock, such as clay.

Anthracite coal has the highest carbon count (more than 90 percent). It has fewer impurities and is more valuable than ordinary bituminous coal.



In general, the deeper a deposit of marine organisms is buried, the higher the temperature and pressure it will experience. Heat and pressure can break some of the bonds of the hydrocarbon chains, releasing small molecules such as methane to bubble upward as natural gas. In most cases, as an oil deposit heats, it releases a larger proportion of natural gas and preserves a smaller proportion as oil. Shallower oil deposits that don't experience extreme heat will usually have a lower proportion of natural gas and a higher proportion of oil.

Fossil fuels are highly concentrated sources of energy. Imagine the difference in the potential energy content between a mass of organic material that was squeezed and heated for millions of years compared to a tree of the same size that is cut down for firewood.

Fossil fuels are incredibly energy-rich in terms of the molecular bonds that hold them together. A great deal of energy is released when hydrogen and carbon molecules combine with oxygen.That energy is transformed into heat energy in car engines and then into kinetic energy (motion) as the heat energy turns the wheels of a car. Fossil fuels can also be transformed into electrical energy to power the appliances in our homes.

The energy of fossil fuels started out as solar energy and was transformed into chemical energy through photosynthesis in plants and the animals that consumed the plants. Burial of these plants and animals preserved this chemical energy, and the materials transformed into fossil fuels. Now, after humans mine and drill these fuels from Earth, they transform the chemical energy into light, heat, motion, and electricity that we use to power our everyday activities.

Student Thinking

What Are Fossil Fuels?

When asked where fossil fuels come from, many students will likely describe something related to dinosaur bones as opposed to plant materials. The word *fossil* immediately creates some confusion among most students.

Ancient plant *Lycopodium squarrosum*, a major source of European coal.

Scenario

Today you teach the class about the formation of fossil fuels. The following question is asked as the starting discussion question to assess what your fifth-grade students already know, and you also use it to end the day's lesson as review.

Question

What is a fossil fuel?

Scientific Answer

A fossil fuel is an energy-rich material, such as coal, natural gas, or crude oil. A fossil is accurately described as any remains from ancient plants or animals, including bones, plant material, imprints, or any other evidence of an ancient living thing. Fossil fuels are created when heat and pressure are applied by natural Earth processes to fossil remains over millions of years, and fossil fuels are actually made mostly from plant material from long ago.

Student Answers (Before Instruction)

Ezequiel: Fossil fuels are fossils, which are found long ago in the era of dinosaurs and ancient plants. And over time, those plants and dinosaurs were covered in mud and turned into fossils.

Martinez: Fossil fuels are natural things like oil and gasoline. Because we get coal from log lost dead dinosaurs. Then we melt it to make oil.

Andrea: Well, when an animal dies, its fossils get broken down into the earth, and after thousands and thousands of years, we found them and we start using them to make energy for our cars.

Student Answers (After Instruction)

Ezequiel: Before I thought fossil fuels were dinosaur fossils and trees, but now I know it's not dinosaur bones, but trees and oils from back then and gases that were trapped underground because of all the pressure.

Martinez: Fossil fuels are made by like dead trees that have fallen. Then the bark, it gets decomposed and turns into coal. Or dead grass or dead plants that got decomposed and make oil.

Andrea: Fossil fuels are made by plants and trees that were pressurized down by sediment and heat. And the plants and the trees got fossilized, and then we're starting to use them to make liquid for our gas and oil.

What Would You Do?

1. Given students' pre-instruction ideas, what concepts seem to be the most important to focus on when teaching fossil fuels?
2. Given students' post-instruction ideas, what would you do next to improve their understanding?

Pictures of Practice

Fossil Fuels and Carbon

When asked to name fossil fuels, many students are able to list coal, oil, and natural gas. However, many students have trouble understanding where fossil fuels come from. In addition to this confusion, students may have trouble linking the carbon that was originally in the ancient living things to the carbon in fossil fuels. The idea that the carbon used now in fossil fuels also existed millions of years ago is a difficult concept for students to wrap their minds around. It may also be hard for students to understand how long it takes fossil fuels to form. Long periods lose meaning for children as numbers begin to exceed thousands to millions of years.

Students: Grade 6

Location: South Gate, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss what fossil fuels are and how they relate to carbon.

Classroom Context

Ms. Walker's sixth-grade science class discussed fossil fuels during their unit on global warming. Most of Ms. Walker's students already learned to name fossil fuels, and most students associate these fuels with global warming. Many students already know that burning fuels releases carbon dioxide (or "bad" gas and pollution) into the air, and that this release of carbon dioxide is bad for the environment.

Video Analysis

In the video, you see that Ms. Walker's students can name fossil fuels. Fossil fuels include coal, natural gas, and crude oil, all of which take about 300 million years to form, with their origins being plant-based materials, not dinosaur bones. During a preinterview, Eliazar describes fossil fuels as coming from dinosaurs and taking only a few hours to form. Eliazar's explanation represents what many of Ms. Walker's students believed about fossil fuels prior to additional instruction. Ms. Walker wanted her student to move beyond the idea that fossil fuels come from dinosaurs, so she approached the question in a different way. Because students knew that carbon dioxide comes from burning fossil fuels, Ms. Walker decided to have her students explain where the carbon in the carbon dioxide comes from. When she asked this question, most of her students were confused, but Emily explained that the carbon was originally in plants and animals before it became fossil fuels. The discussion about carbon continued beyond Emily's explanation, and students heard about how carbon bonds in fossil fuels are strong, making them good energy sources. After this discussion, many students were still confused, although they seemed to realize that fossil fuels come mostly from ancient plants (not just dinosaurs). You will see one student, Samantha, mention carbon in her explanation of fossil fuels, during a post interview. Yet, Samantha admits that she does not understand fossil fuels even after the discussions.

Reflect

How can you help students better understand fossil fuels?

Think about why fossil fuels are challenging for students to comprehend. How would you approach teaching this topic? What is the benefit of focusing on carbon that helps students move beyond explaining fossil fuels as coming from dinosaurs and dinosaur bones?

Carbon Emissions

Just as energy is transformed through photosynthesis and burning, matter involved in these processes is also transformed. The ancient plants and animal materials that became fossil fuels were fundamentally different materials from the coal, oil, and natural gas they became. Chemical reactions changed the starting substance into a different material.

When we burn fossil fuels and convert them to a form of energy we can use (light, motion, heat, and electricity), that material is also changed. Though we know that matter cannot be created or destroyed, it can be confusing to fill a car's tank with gas and have it "disappear" as we drive the car. The discrepancy can be understood when we know that the primary products of combustion are invisible gases. Combustion changes the location of carbon that has been buried beneath Earth's surface for millions of years, releasing it into our atmosphere.

Because of the increasing concentration of carbon dioxide in Earth's atmosphere, people point to the negative impact from fossil fuels. Further, people question whether fossil fuels can continue to supply our demand for energy for many years to come. Today we find ourselves in a conundrum. On the one hand, fossil fuels revolutionized our societies and made our current lifestyles possible. Our success as a nation is inextricably linked to what we have accomplished by using fossil fuels. However, we also know that these amazing energy sources are limited in quantity, and we know that our systems for extracting them cause environmental damage. We also know that we are sending large amounts of carbon dioxide into the atmosphere when we burn them, resulting in amplification of the Greenhouse Effect and leading to climate change.

Through combustion of fossil fuels, such as coal, carbon dioxide and water are released into the air.

One of our biggest concerns today is figuring out how the world can meet our demands for energy in a way that reduces our use of fossil fuels.

Combustion of Fuels. The burning of fossil fuels releases the carbon that was originally stored in plant and animal matter as carbon dioxide. Some countries have vast amounts of underground coal available to them. Coal can be mined, processed, and burned relatively cheaply and often does not need to be transported great distances. These factors make coal an inexpensive energy source. As countries expand economically and develop their industries, they often burn more coal. While the United States underwent this transition to coal-based power in the 1800s, other countries, such as China, are in the process of building new coal-fired power plants for electricity generation today.

The amount of CO_2 that is produced from each energy source varies. Common gasoline releases less CO_2 for the energy we recover compared to coal products. Burning natural gas for energy produces even less CO_2 per unit of energy produced than either gasoline or coal. Surprisingly, burning wood produces almost the same amount of carbon dioxide as an equal amount of energy produced from some forms of coal.

The United States currently produces approximately 6 billion metric tons of carbon dioxide per year. Our present carbon emissions come from petroleum (primarily used for transportation needs), coal (primarily used for electricity production) and natural gas (primarily used for commercial/residential heating).

Students may have heard about carbon emissions or carbon dioxide, but their understanding of combustion of fuel to produce carbon dioxide is probably not well developed. When asked to explain where the gasoline has gone when a car's gas tank has gone from full to empty, many students respond that the gasoline turned into energy or evaporated into the air. More recently, students are starting to recognize that the gasoline reacts with oxygen to form gases that enter the air, but they can still lack a solid understanding of how liquid gasoline becomes gaseous carbon dioxide and water vapor.

Teaching Tip

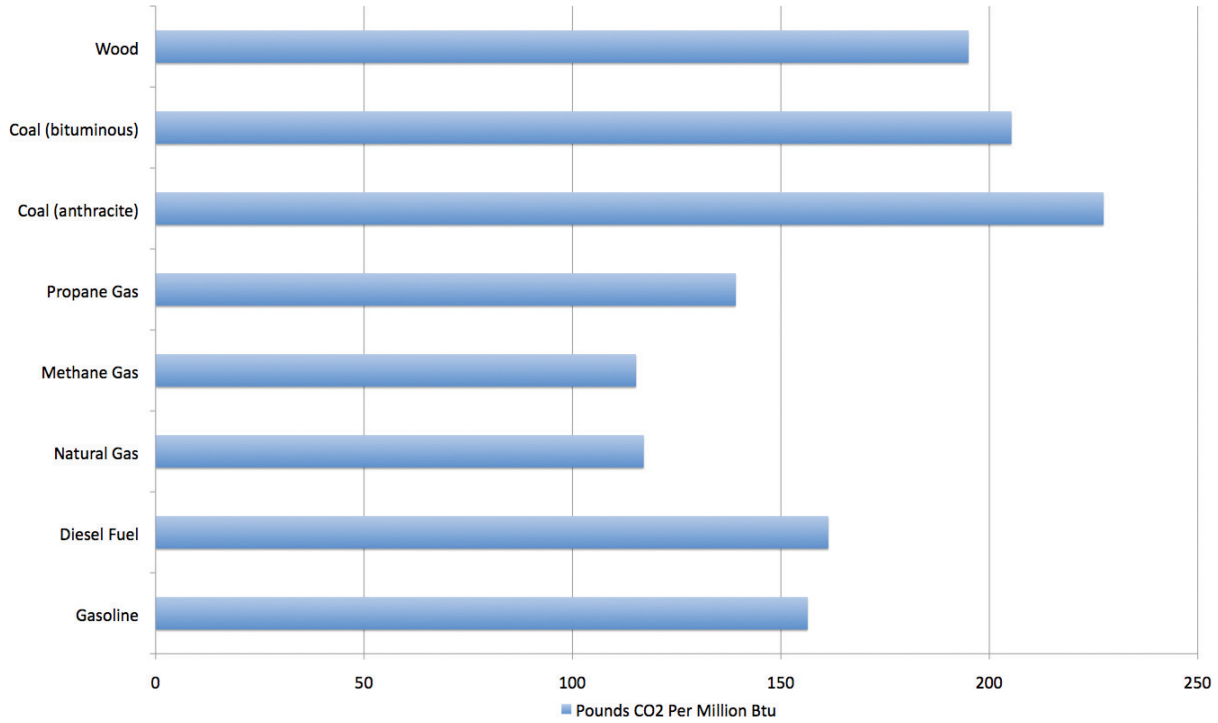
The process of burning is a visual experience that students know well. As such, we tend to think *burning* means the same thing to everyone. Be aware that it may mean very different things to different students within the same classroom. Pay particular attention to when and how students use the word *burn,* and try to establish a shared meaning for it among your students. For some students, *burning* may mean that something "evaporates" or "vaporizes" or simply "goes away." For others, it may be likened to decomposition. Still other students may use *burning* to describe a process by which matter turns into energy. The goal is to have all students see *burning* in terms of a chemical reaction that does not create or destroy matter.

In Chapter 2 you read about combustion, in which a fuel source is oxidized. This fuel source may be plant matter, such as wood, or fossil fuels or the wax that makes up a candle. In all cases, these fuel sources are mostly made of carbon and hydrogen and potentially oxygen atoms. When the fuel reacts with oxygen, a chemical reaction occurs. Energy is transformed from the chemical energy in the fuel into light, heat, or motion. The material products are carbon dioxide and water vapor. Following is the chemical reaction that occurs when methane burns: $CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$.

Notice how similar this equation is to cellular respiration that occurs as our bodies "use" or "burn" food to fuel our body functions: $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$.

Both of these processes begin with a carbon-based material—either a food or a fuel. They react with oxygen to produce carbon dioxide and water vapor. All these processes—burning wood, fossil fuels, or food in our bodies—do similar things chemically to meet specific energy needs.

EMISSION COEFFICIENTS



Fossil fuels, as well as wood, give off varying amounts of carbon dioxide in relation to their energy output. This graph shows that burning wood and coal produce more carbon dioxide compared to burning other fossil fuels for the same amount of energy output. Data for this graph can be downloaded from the U.S. Energy Information Administration emission coefficient page: Available at http://www.eia.doe.gov/oiaf/1605/coefficients.html.

In the Classroom

Learning From a Burning Candle

Recording the mass of a candle both before and after burning makes an easy demonstration of combustion that can be completed in your classroom (Environmental Literacy Project). During burning, the mass of the candle decreases. Students may ask (or you may ask them), "Where did the missing mass go?" Students may focus their explanations on the candle melting, but probe further, so students must explain what happened to the liquid wax. Students might also focus on the smoke, but continue asking them to explain what they mean by *smoke.* (e.g., What is smoke made up of?). To check understanding, you can also light and burn a match, and ask students what happens to the wood of the match as it gets shorter.

Materials

- Digital Balance sensitive to 0.1 or 0.01 grams
- Good-quality candle, at least votive size
- Lighter
- Paper/chart to record observations
- Match (optional)

Directions

1. Prior to conducting the demonstration with students, test the demonstration on your own. Depending on the sensitivity of your digital balance and on the quality of your candle, you may get inconsistent results. Good-quality candles that will stay burning even when the building's air system is on and a balance sensitive to 0.01 grams will ensure convincing results for your students. If your balance is sensitive only to 0.1 grams, consider using a slightly larger candle and burning it over an entire class period to get valid results.
2. Gather digital scale, candle, and lighter, and make sure that students can see the demonstration.
3. Turn on and zero out the digital balance. Weigh the candle and record the start mass.
4. Light the candle, and let the candle burn for at least ten minutes. During the burning, have students write and discuss their predictions for what will happen to the candle mass. Ask students to make a prediction whether the mass will go up, down, or stay the same, and to explain the reasoning behind their predictions in writing and with their partner.
5. After at least ten minutes, record a second mass reading for the candle. Have students discuss whether the second mass reading supports or disproves their prediction. Use the following questions to generate discussion.
6. Variations and Extensions: Variations on this activity might include placing the burning candle inside a cool glass jar to collect moisture. Some teachers may even monitor carbon-dioxide levels using probeware as the candle burns. Also, consider taking additional readings across the class period to establish patterns for the decrease in mass.

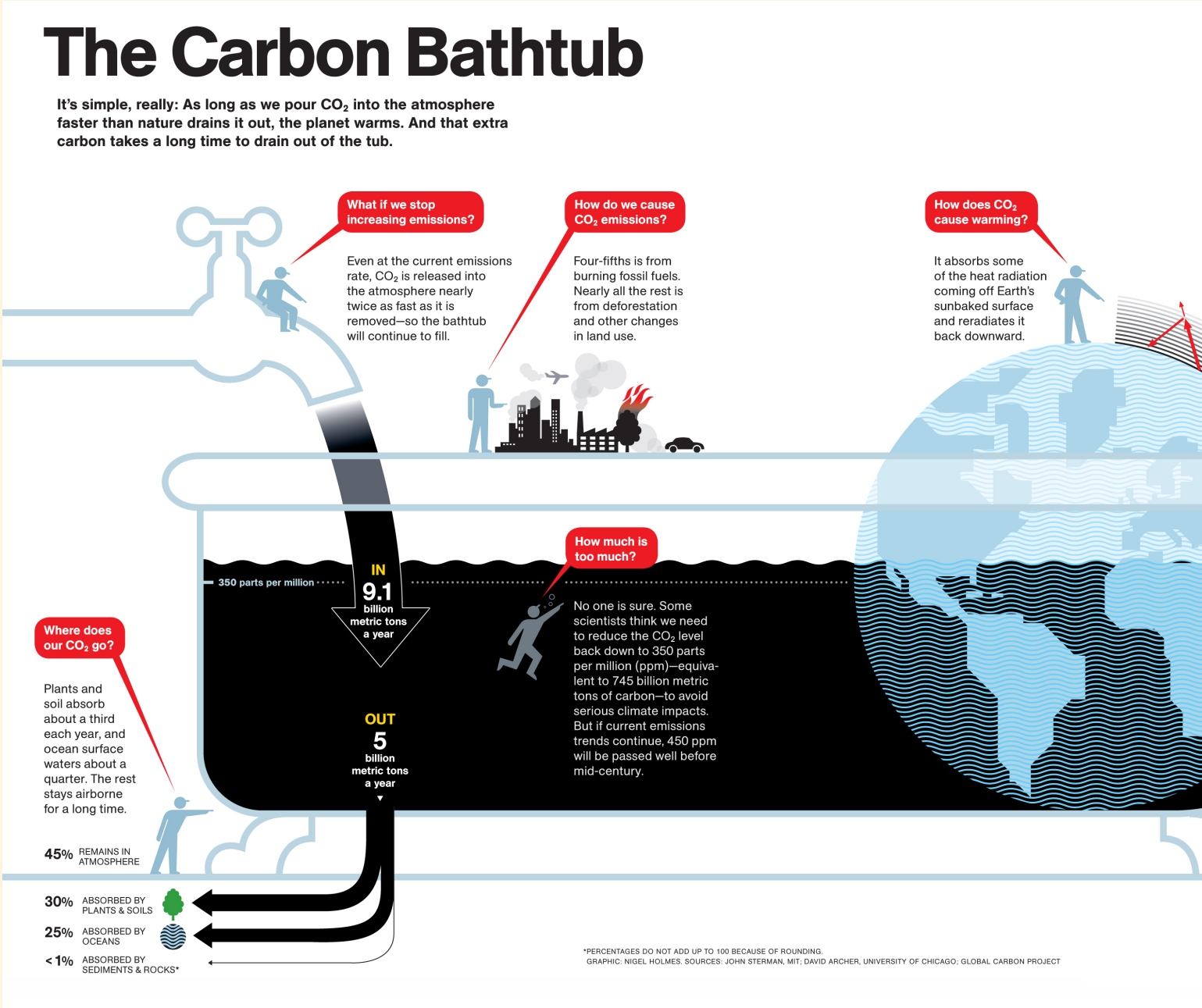
Ask Your Students

1. Where does the mass of the candle go as it decreases?
2. How do the materials change when the candle burns?
3. How does energy change when the candle burns?
4. How is the candle burning like burning gasoline in your car or propane in your barbeque grill?

Representations of Science

The Atmospheric Bathtub

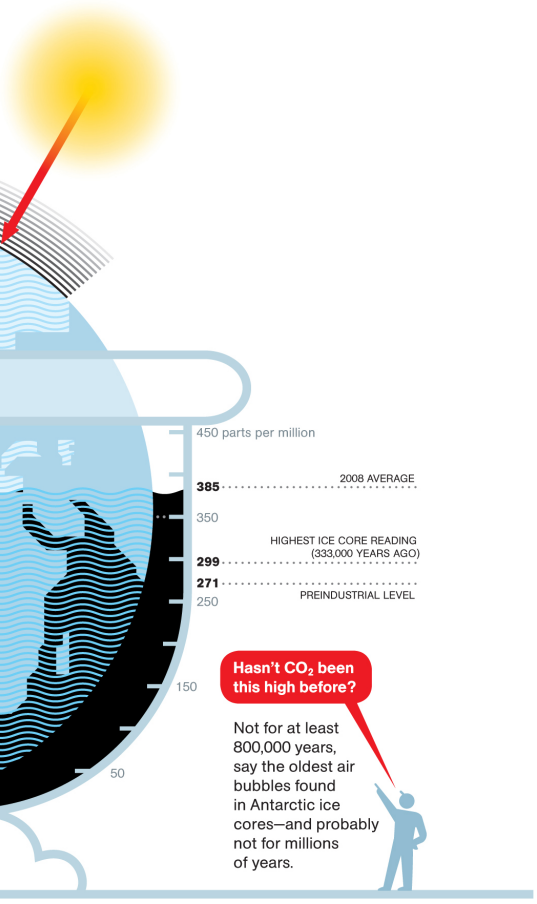
One representation of carbon emissions that has been used with adults is the atmospheric-bathtub analogy. The atmospheric-bathtub analogy likens inputs of carbon dioxide into the atmosphere to water filling up a bathtub. Processes that take carbon dioxide out of the air, such as ocean absorption and photosynthesis, are likened to water running down the bathtub drain. The idea is that the bathwater level will stay the same if the amount of water entering the tub is equivalent to the amount of water draining out of the tub. Like the bathtub, our

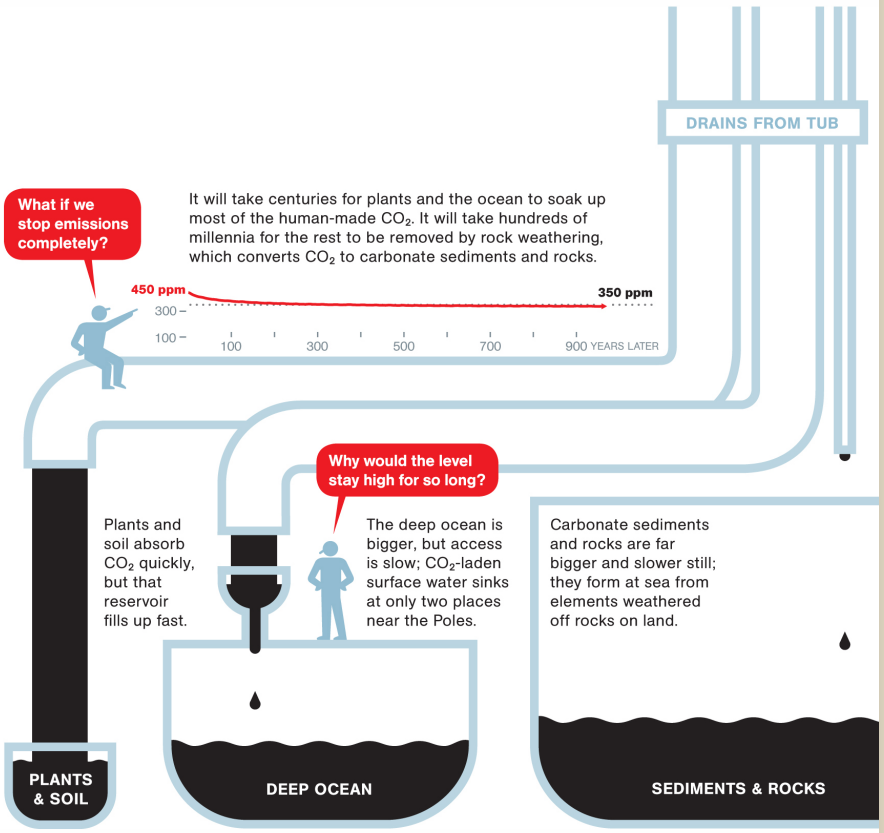


atmosphere is filling up with carbon dioxide, but the "drain" is not removing it as fast as it enters our atmosphere.

On the surface, this analogy seems simple enough that even young children may understand the general principles. Yet, as Sweeney and Sterman (2000) show, even adults have difficulty with this concept, especially when the atmospheric bathtub becomes more complicated than our bathtubs at home. For example, our atmospheric bathtub has multiple drains (i.e., carbon sinks) compared to the one drain on our bathtubs at home. The capacities of those drains are different and work on different time scales. The delayed effect of one drain compared to another may confuse students given that water generally runs very quickly down the drains found in our bathtubs.

Think about the benefits and limitations of the atmospheric-bathtub analogy. How could such an analogy be used to help students understand large-scale emissions? Where might students struggle with using this analogy?





Pictures of Practice

A Burning Candle

Combustion is a challenging concept for students to understand. At the visible scale, it seems like matter disappears as it burns. A match burns and gets shorter. A gasoline tank becomes empty. A candle burns until all the wax is gone. How do students make sense of these experiences, especially when they do not fully understand gases as a form of matter? All these experiences can be explained by fuels (such as wax, wood, or fossil fuels) being oxidized and giving off carbon dioxide and water as products. So how do teachers use everyday experiences, such as burning a match or a candle, to help students understand that solid or liquid fuels become gases? One suggestion is the candle activity described on page 59, **In the Classroom: Learning From a Burning Candle.** By simply taking an everyday experience, like a burning candle, and asking students to explain where the wax material goes, you can open the door for rich discussion about combustion.

Students: Grade 5

Location: South Gate, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss what happens to materials and energy as a candle burns.

Classroom Context

The candle activity occurred in the middle of Ms. Walker's lessons on climate change. Ms. Walker wanted to teach about combustion of gasoline in cars but used the candle activity first to help students make the connection between fuel becoming gases during the burning process.

Video Analysis

At the beginning of the candle lesson, Ms. Walker asks her students to make predictions about whether the candle would gain or lose mass as it burns. Steven hypothesizes the candle will gain mass, explaining that it will have "more atoms." However, Amaya suggests that the candle will become lighter, because "CO_2 is rising." Next, students watch the candle burn for several minutes, and eventually the candle loses one gram of mass. Ms. Walker then asks her students to explain what happened to the mass. You will see that some students quickly identify carbon dioxide, while others struggle to explain where the matter went. During the post interview, Ms. Walker expresses her satisfaction with the activity, explaining that she thought many students understood how burning puts carbon dioxide into the air and that matter never actually "goes away." This understanding is confirmed by post interviews with Alan and Samantha. Afterward, Ms. Walker uses the candle activity as a bridge to discussing burning gasoline in cars.

Reflect

How would you help students connect combustion and carbon dioxide?

During the classroom discussion, several students use terms such as *goes away* or *rises.* Do students really mean that matter disappears? How could you probe for further information? In their post interviews, Samantha and Alan are able to connect what they had learned from the burning candle to carbon dioxide entering the air, but their understanding of the actual burning process is limited. What concepts would you focus on when teaching the process of burning? Why?

References

EIA. Annual Review. 2006.

EIA. "History of Energy in the United States: 1635–2000." www.mnforsustain.org/energy_in_the_united_states_1635-2000.htm. June 6, 2010.

Sweeney, L. B., and J. D. Sterman. "Bathtub Dynamics: Initial Results of a Systems Thinking Inventory." *System Dynamic Review,* 16.4 (2000): 249–286.

Teaching Resources

Basic information about coal: http://tonto.eia.doe.gov/kids/energy.cfm?page=coal_home-basics

Basic information about natural gas: http://tonto.eia.doe.gov/kids/energy.cfm?page=natural_gas_home-basics

Basic information about oil: http://tonto.eia.doe.gov/kids/energy.cfm?page=oil_home-basics

California Education and the Environment Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm

Carbon Bathtub Article: http://ngm.nationalgeographic.com/big-idea/05/carbon-bath

EIA Energy Flow figure: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_3.pdf

Population versus Energy consumption: http://www.worldpopulationbalance.org/population_energy

U.S. Department of Energy Resources: http://fossil.energy.gov/education/energylessons/

4 A Look at Climate in the Past

by Nicole D. LaDue and Lindsey Mohan

Climate scientists commonly show graphs that depict Earth's temperature thousands of years ago. Students may wonder how scientists can possibly know what Earth's climate was like in the past when no instruments were available to measure it.

Processes such as annual growth in trees and accumulated layers of snow have preserved natural records of climate conditions throughout Earth's history. This chapter is about how scientists read and interpret historical records of climate and how they reconstruct these records to communicate about our past. These reconstructions involve collecting samples from the present day, such as tree rings, ice core, pollen or coral samples, and so on, that provide scientists with a window into the past. While humans may not have been around, or may not have had sophisticated instruments to measure climate, living organisms have retained their own records that we can study.

In this chapter we take a closer look at one of the most controversial reconstructions of past climate. This graph is now known as the hockey stick. After discussing both instrumental records and reconstructions such as the hockey stick, we take a closer look at two types of proxy data collected by scientists—ice-core and tree-ring **proxy data.**

Global Temperature Records

Anyone who examines instrumental climate records will notice that the earliest records of temperature are from the mid- to late-1800s. Before that time, very few reliable scientific instruments existed. In order to extend our understanding of climate any farther into the past we must look at natural processes that recorded changing climate conditions. Scientists refer to this data as proxy data. A proxy is something that can be measured that fluctuates with the changing temperature and is used to understand climate variations in the absence of actual temperature data.

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.d 3.5	Living Things in Changing Environments
Grade 4	4.6	
Grade 5	5.2.f 5.6 5.1.1	
Grade 6	6.1.3 6.7	
Grade 7	7.4.e 7.4.g 7.7	Extinction: Past and Present
Grade 8	8.9	

Perhaps the easiest process to understand how nature can form a record of conditions is the growth of annual tree rings. During years that conditions of temperature and precipitation are conducive for tree growth, trees produce relatively wide annual rings. Conversely, when the combination of temperature and precipitation is too high or too low, trees will produce a narrower annual growth ring. By examining ring widths from many trees and comparing them to rings that were produced under known conditions, scientists can determine the climate conditions that the trees lived through.

Several other natural processes fluctuate with changes in temperature and preserve those records within physical structures. Scientists have learned to unravel clues recorded in layers of ice, corals, and stalactites in caves to determine past temperatures. Temperature data that are determined from natural records are called proxy data. The word *proxy* means "something that stands in for another thing or serves as a substitute." By comparing records produced by several processes, scientists have reconstructed the climate history for many different regions, and for Earth as a whole.

The Hockey Stick

One of the most notable representations from the climate science field is known as the hockey-stick graph. The hockey-stick graph has been used to show that our recent warming is happening and that it is caused by human activities. In 1999, a scientific paper came out that led to one of the biggest modern scientific controversies. Michael Mann, Raymond Bradley, and Malcolm Hughes published a paper that gathered several sets of proxy data for global temperature and demonstrated that temperatures started rising at a faster rate in the 20th century (Mann et al. 1998, 1999; for summary see Appell 2005). This line graph has a gentle slope, indicating a slowly declining trend in temperatures from 1000 through 1900. The graph takes a sharp upward turn

CHAPTER OVERVIEW

Climate scientists use data from tree rings, layers of ice, and other sources to reconstruct past climates. While we have no instrumental records of this time, natural processes that record climate conditions can provide us with information about our past.

Layers of snow that fell during winters and did not melt away during summers accumulated into thick ice sheets on Greenland and Antarctica. When scientists drill into these ice sheets and retrieve cores of ice, they analyze water molecules from the layers to determine the global temperature when that snow fell. Layers of ice also contain tiny air bubbles that were trapped in the snow. Analyses of these air samples reveal the relative abundance of gases in the atmosphere when the snow fell. Like ice cores, tree rings also show a record of annual climate cycles. The thickness of tree rings can be affected by temperature, rainfall, availability of sunlight, carbon dioxide, soil pH, wind, cloud cover, and nutrition. Scientists use this information to help reconstruct the variations in climate that the tree has lived through during its lifetime.

with a steep slope indicating increasing temperatures for the past 100 years. The upward turn occurs just a bit after the beginning of the Industrial Revolution, when humans started adding large amounts of CO_2 to the atmosphere by burning fossil fuels. The graph is called the hockey-stick diagram because it resembles the shape of a hockey stick.

The graph appeared in the 2001 Third Assessment Report from the UN Intergovernmental Panel on Climate Change (IPCC). The IPCC report represents the scientific consensus about climate change. Since some people expect significant economic impacts from regulating CO_2 production as we decrease our use of fossil fuels, policy makers and others became greatly concerned that climate change had been connected to human activity. Many people, including some scientists, began questioning Mann, Bradley, and Hughes about their data and even their personal motives for presenting their findings.

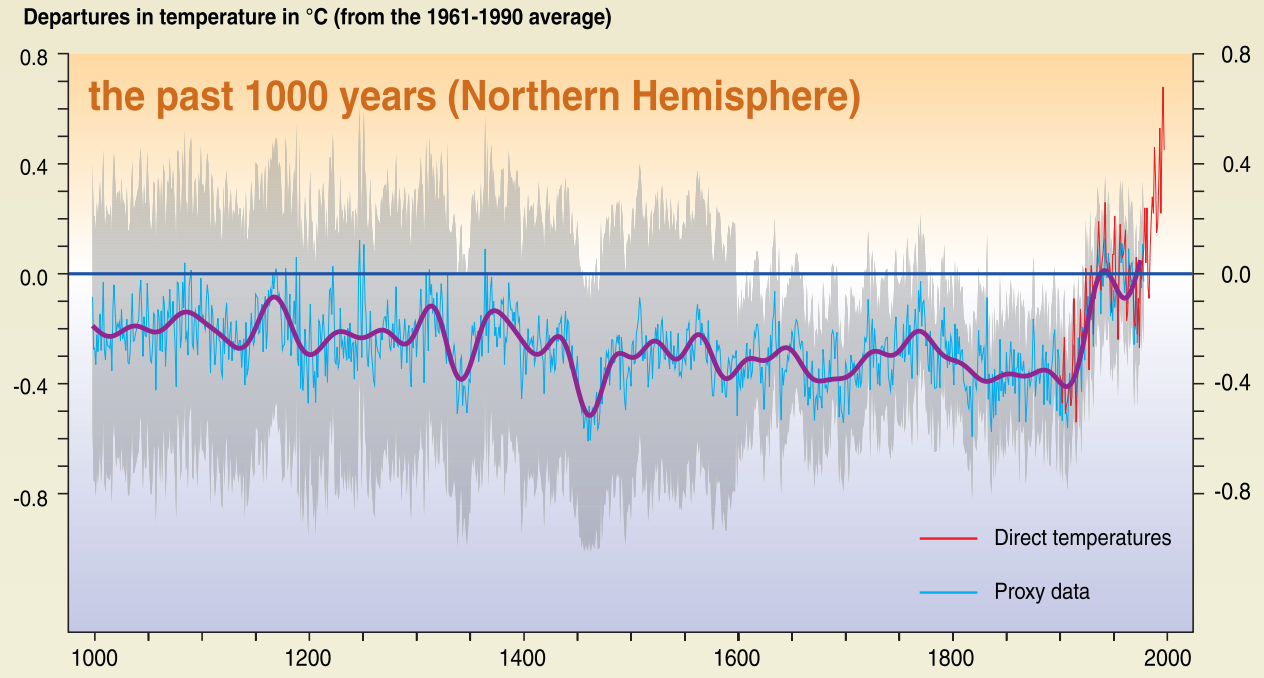
The Controversy. The controversy surrounding the report included accusations by members of U.S. Congress that the scientists may have had ulterior motives for financial gain by publishing their data. The congressmen asked the National Academies of Sciences to create a committee to investigate the statistical methods that the scientists had used. The committee did find some errors in the statistical analysis but, with corrections, confirmed all of the major findings of the paper. Nevertheless, the controversy has continued as statisticians, climate scientists, and the public have picked at details of the findings.

Because the graph includes temperature estimations from proxy data, it involved a known range of possible error. Proxy data allows us to estimate temperature changes, but problems with data collection and incomplete records can lead to imperfect data. Scientists have attempted to take out each set of data to see if one set was unreasonably changing the result and have found that the overall trends on the graph have remained consistent. The possible range of error in the hockey-stick diagram shows up as gray ranges above and below the blue reconstruction line.

More Certainty With Instrumental Records. While controversy around the hockey-stick graph centered on proxy data, instrumental temperature records in present day indicate that global temperature has risen by 0.74 degrees Celsius in the last 100 years. Multiple proxies have shown that the global temperature was cooling until the Industrial Revolution. Also, instrumental measurements of carbon dioxide at the Mauna Loa Observatory on Hawaii since the late 1950s show a 30 percent increase in the concentration of atmospheric CO_2 since that time.

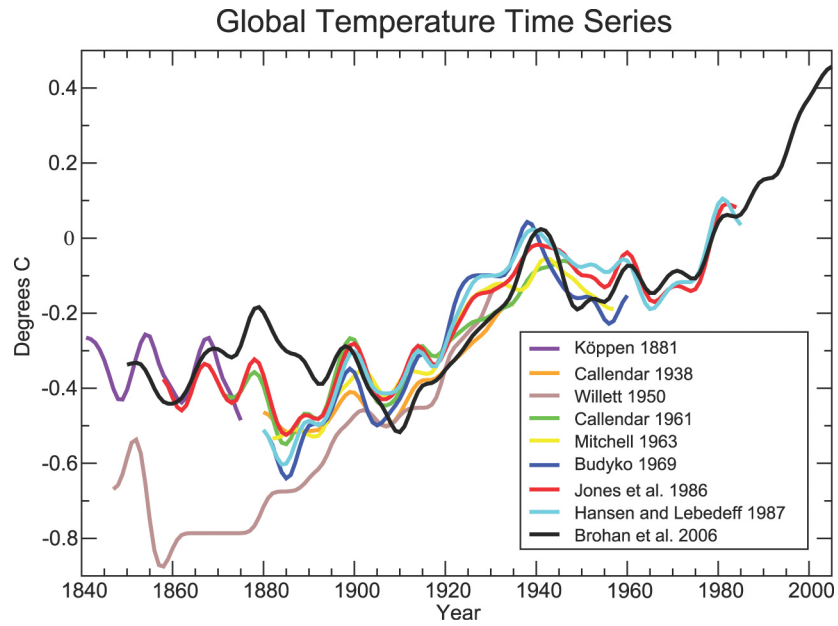
When interpreting climate-science graphs, students may be confused on a couple of points. Even given instrumental records, not all scientific studies that make estimates of global temperature produce the same results. As the graph Instrumental Temperature Records shows, estimates of global temperature do not match exactly across

THE HOCKEY STICK



The hockey-stick graph includes more recent instrumental temperature data, as well as reconstruction using proxy data.

INSTRUMENTAL TEMPERATURE RECORDS



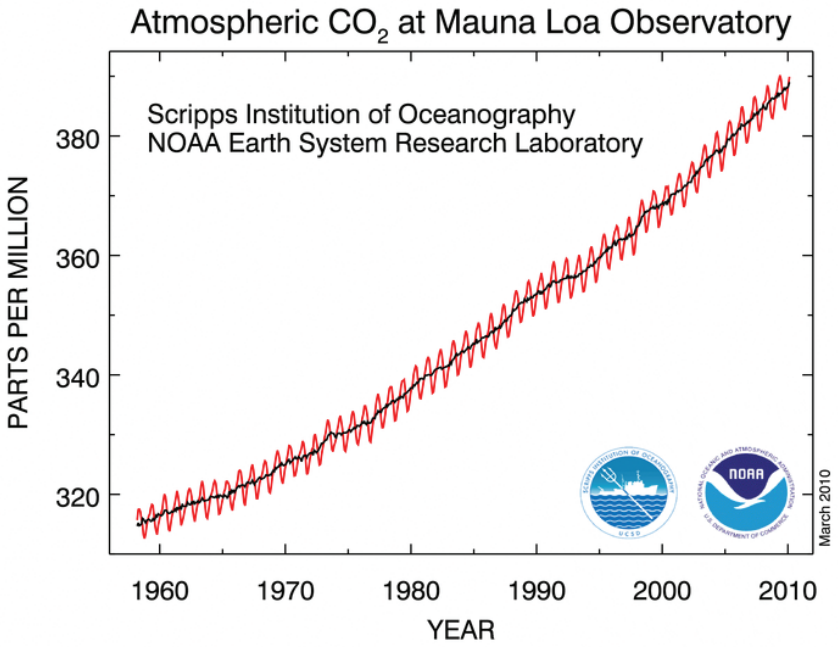
This graphs shows several scientific studies of global average temperature during the past 150 years of instrumental records. From IPCC (2007) AR4.

all the research groups who publish such results. During the 1800s, the variation between different group's estimates was much greater but even after 1900 results did not show an exact match. Much of this variation is due to the different algorithms that research groups use to fill in (or omit) missing values over regions where temperature records are few and far between. When several science studies are pulled together, however, we see a very similar trend, or pattern, among the different studies.

Scientists also estimate uncertainty, and many climate-change graphs depict this uncertainty. Oftentimes students take a scientific observation as fact, but the range of estimates on the Instrumental Temperature Records graph shows that observations can be interpreted in different ways. Though each estimate of global temperature is slightly different in the details of how it was calculated, comparing the full range of values across studies reveals patterns that hold true across all the data. The fuzzy gray range on the hockey-stick graph shows more uncertainty regarding temperature prior to the 20th century, with scientists becoming even more certain as instrumental records improved in accuracy.

Using instrumental records and proxy data helps scientists construct models for climate change. This topic will be more thoroughly discussed in Chapter 5, but a brief explanation is given here. Scientists used Global Climate Models (GCMs), in which they input proxy data and current instrument measurements, and attempt to determine how the climate will change in the coming years. A big limitation of climate modeling is that it does not do a good job of predicting climate change on a regional scale. Regional-scale models would be helpful in showing us where and how precipitation patterns and weather patterns may change in a regional or local area. For example, you might observe changes in your local climate such as having more frequent and heavier snow in the winter or earlier blooming of particular trees and flowers. However, these observations do not provide clear evidence of climate change, and many of the current climate models do not focus on local changes that people may observe in their own backyards.

MAUNA LOA CO_2 RECORDS



The iconic Mauna Loa graph depicts atmospheric carbon-dioxide levels. It shows seasonal changes each year, as well as a steady increase in CO_2 since records began in the late 1950s.

Student Thinking

The Mauna Loa Graph

The Mauna Loa graph shows two patterns: one pattern (red line) shows seasonal changes in CO_2 that correspond with growing patterns in the Northern Hemisphere; the other pattern (black line) shows a steady rise in average CO_2 for the last 50 years.

Scenario

You have just finished a lesson on the Mauna Loa graph with your students. To assess student comprehension of the lesson, you give students homework to take home. Following are answers to one of the homework questions about the Mauna Loa graph.

Question

Explain why carbon-dioxide levels are going up in the Mauna Loa graph?

Scientific Answer

Many scientists point to the industrialized world as the culprit of the overall rise in carbon dioxide in the atmosphere. Major pollutants such as car emissions and industrial manufacturing are putting CO_2 into the air faster than it can be removed through the natural carbon cycle, and changes in land use are reducing natural carbon sinks that remove carbon dioxide from the air.

Student Answers

Emily: It goes up, and it goes up pretty quick. Mainly, I think it's all the actions that we do. All the things that we do are mainly causing CO_2. Like especially when we're digging for fossil fuels, or like coal, the technology we use isn't energy efficient, and it's putting more CO_2 into our world. And the when the actual coal, when they burn it, it puts off CO_2 for our electricity, so every time we use our electricity we're causing more CO_2.

Samantha: I think like since we started using more technology and stuff we don't really think about what we're using or trying to save energy and stuff. So we really don't think about what we're using and we just have used a lot of energy and its gone up to our atmosphere.

Eliazar: Because we made more houses we cut more trees and we make — we expanded the population. And we use more cars, more energy, and it rises more carbon dioxide.

Burhon: I don't really know how to explain it. Polluted gas would just probably be like more particles inside the gas that are burned off or made from other materials and stuff that are not sanitary for the environment.

Xena: I think it keeps getting higher and higher because we use more carbon dioxide every year.

Marc: Yeah, it increases. We pollute the air with more bad gases I think.

What Would You Do?

1. How would you grade these answers? What do these answers show that students have learned? What do the answers say about the concepts students did not learn or still do not understand?
2. How could you reteach this topic to ensure that all students understand the rise in CO_2 shown in the Mauna Loa graph?

Pictures of Practice

Mauna Loa Carbon-Dioxide Records

The Mauna Loa graph is one of the most popular representations used to show rising carbon-dioxide levels. Because the graph uses only instrumental measurements and recordings have been taken in the same location at the Mauna Loa Observatory, some of the complications that come with interpreting other climate-change graphs are not present when looking at the Mauna Loa graph. However, students may still be confused about how to read the graph, and what causes the different trends (see **Student Thinking: The Mauna Loa Graph,** on page 62).

Students: Grades 6 and 8

Location: California (in coastal communities)

Goal of Video: The purpose of watching this video is to see students interpret the Mauna Loa graph and explain their ideas about what causes the upward trend in CO_2.

Classroom Context

Students in this video live in California urban and suburban communities. The interview clips shown in this video were taken during the spring of the school year after both sets of students learned more about climate change. The first part of the video shows sixth-grade students describing their ideas about the Mauna Loa graph. The second half of the video shows eighth-grade students answering the same question. Think about the different types of responses you hear from students in the same grade as well as differences between grade levels.

Video Analysis

This video focuses on how students explain the increasing levels of carbon dioxide over time as opposed to seasonal fluctuations. The eighth-grade students have seen the graph before, but the sixth-grade students have not. The sixth-grade students have diverse ideas about causes of the rising CO_2 levels, such as not being energy efficient, burning fossil fuels (especially in cars), deforestation, increasing population, and increasing technology. Comparatively, the eighth-grade students focus on carbon dioxide, or "bad gases." It is important to note that the Mauna Loa graph depicts both seasonal changes in atmospheric CO_2 and change over time (see **More Certainty With Instrumental Records,** on page 60, for more information). It is likely easier for students to understand the change-over-time trends first, and many students have ideas about why this trend is happening, as shown in the video. The other trend—seasonal variation—is much more complicated. When students are asked to explain this trend, they often point to winter being colder and summers being warmer as the reason for changes in carbon dioxide. Some students may say that we emit less carbon dioxide in the summer compared to the winter. Few students identify plants as corresponding to the zigzag pattern. Because of this complicated pattern, the Mauna Loa graph may be inappropriate for some students. Students who do not have a good understanding of photosynthesis will struggle to make sense of the seasonal pattern.

Reflect

Given these student ideas, what would be your next step for teaching about carbon dioxide levels? The sixth-grade students focused on human actions that contribute to rising CO_2 levels, while the eighth-grade students focused on the CO_2 itself as causes for the overall increasing trend in the Mauna Loa graph. If this diversity of ideas were shared in your classroom, what would be your next step? What student ideas would you focus on in your instruction? Why?

Case Study

Ice-Core Proxy Data

What Is an Ice Core? What Information Can Scientists Get From Ice Cores?

Each year, as Earth revolves around the sun, seasonal changes in weather occur due to the tilt of Earth's axis. During cool periods of Earth's history, in places such as Greenland and Antarctica, snow that accumulated during the winter season did not melt entirely during the summer. The leftover snow each year became compacted into layers of ice, forming glaciers. The annual layers of snow trapped small bubbles of air and included particles from volcanic ash eruptions or wind-blown dust. Seasonal changes resulted in differences between winter and summer layers, and the layers contain wind-blown particles that were deposited on the snow's surface during windy spring seasons.

Scientists obtain ice cores from thick ice sheets, using a drill and hollow tube. Scientists drill into the ice in places where it is very thick. For instance, in Greenland, they removed ice from a drill-hole measuring nearly two miles deep (~3000 meters or 11,000 feet). A core such as this from Greenland may represent 110,000 years of ice accumulation; however, ice cores from Antarctica have provided a historical record going back 800,000 years.

Once obtained, ice cores are stored in special freezers to preserve the information they contain, and small samples of the ice are shaved off the cores for analysis. The variations in the layers can provide scientists with information about past climate over time. Layers of ice containing ash from volcanic eruptions make it possible to determine precise dates when the snow fell: analysis of igneous rocks provides information about when eruptions took place. Therefore, ice layers with ash serve as bookmarks in time for ice cores.

How Does Ice Provide a Record of Atmospheric Gases?

In addition to providing a snapshot of the annual precipitation and recording events such as volcanic eruptions, the ice contains small bubbles of air that were trapped as the snow was compacted into ice. The gases in these bubbles represent samples of the atmosphere at the time the snow fell. Scientists can analyze the samples to find past concentrations of gases such as methane and carbon dioxide. Higher methane levels in an ice core indicate that Earth had a relatively large amount of biomass present at the time the snow fell, often in the form of widespread wetlands where decomposing plant material produced methane. Carbon-dioxide levels in air bubbles of ice cores changed as global temperature increased or decreased over time as Earth went through **ice ages** and **interglacial periods.**

What Do Ice Cores Tell Us About Climate Change and CO_2?

In addition to analyzing the gas in the bubbles trapped in the ice core, the ice itself offers information about past temperatures of the atmosphere. Ratios of the oxygen isotopes present in the water can help scientists reconstruct the paleoclimate (ancient climate). **Isotopes** are naturally occurring small quantities of an element that have a different number of neutrons. Atoms contain subatomic particles called protons and neutrons in their

The bubbles visible in this piece from an Antarctic ice core sample contain carbon dioxide and other gases that were trapped in the ice when formed thousands of years ago. Researchers carefully crush the piece and capture the gases that escape when the bubbles break. This allows them to better understand what carbon-dioxide levels were over time.

nuclei. Adding the number of protons to the number of neutrons gives us the atomic weight. Atoms that have the same number of protons are considered to be the same element. All oxygen atoms have eight protons. Most oxygen atoms have eight protons and eight neutrons, giving oxygen an atomic weight of 16. These are called oxygen-16, written as ^{16}O. A small percentage of oxygen atoms have eight protons and ten neutrons. These atoms are called oxygen-18 (^{18}O). Because the ^{18}O atoms are heavier than the ^{16}O atoms, ^{16}O evaporates more easily. Warm air, which contains more energy than cold air, allows a higher proportion of the heavier ^{18}O to evaporate. Therefore, when climate is colder, more ^{18}O will be left behind in the oceans and more ^{16}O evaporates into the atmosphere where it can fall as snow. The snow that falls during cold periods has a lower ^{18}O to ^{16}O ratio than warmer periods. Scientists measure the ratio of ^{18}O to ^{16}O in ice cores as a proxy, or related measurement, for the ancient atmospheric temperature.

Scientists have done much research to determine what causes ice ages and warm periods. Scientists currently understand that it is most likely a combination of factors such as the slight wobble of Earth's axis of rotation that occurs over thousands of years (known as **Milankovitch cycles**), the position of continents, concentration of greenhouse gases in the atmosphere, ocean currents, and variations in the sun's intensity. Scientists have matched the historic temperature changes from the oxygen isotopes with changes in the carbon-dioxide levels measured from the gas bubbles in the ice cores. What they see is that CO_2 concentrations start to rise approximately 800 years after the temperature starts to rise. This indicates that the CO_2 concentration in the atmosphere does not begin the warming trend bringing Earth out of an ice age. However, because carbon dioxide is a greenhouse gas, it will amplify, or further, the warming trend. Scientists have determined that roughly half of the warming from a glacial to an interglacial period is caused by CO_2 in the atmosphere.

What are the Limitations of Ice Core Data?

As with any analytical technique, ice cores have some limitations. One limitation is that as ice is being analyzed, the ice only represents the atmospheric conditions during snowfalls and not for the entire seasonal cycle. Additionally, ice layers may not remain completely intact as they move downhill due to gravity under the weight of the large mass of ice. As a result, the ice can be deformed, or changed, by the flow of the ice. This can introduce errors. A way to counteract this limitation is by taking multiple cores from nearby locations; however, this is an expensive option because ice-core drilling is quite costly. One very important limitation of ice-core data facing scientists today is the rapid melting of many high-latitude glaciers as a result of global warming. As the glaciers melt, we are losing the ice record from which we can extract information about past climate changes. Global warming is causing the loss of the best source of data to understand how climate has changed in the recent past.

Teaching Tip

To demonstrate how ice cores trap gases in them, freeze club soda in ice cube trays, and then place them in water to simulate an ice core. Have students listen into the cup to hear the *fizz* the frozen soda makes. They will also be able to see the bubble-shaped spaces left in the ice once the gas has escaped. Make sure to explain clearly that what they hear and see in the soda is carbon dioxide, while the gases in ice cores are made of a mix of different types of gases.

Case Study

Tree-Ring Proxy Data

What Are Tree Rings?

Have you ever noticed the pattern on a piece of wood and wonder where it comes from? Those patterns are related to changes in the rate of the tree's growth throughout the year. Trees grow by making food through photosynthesis, involving atmospheric carbon dioxide, water, and sunlight. Because tree growth depends upon these and other components, they grow faster when there is more sunlight and water (among other things) and slower when there is less. These factors change throughout the year as rainfall and sunlight change with the season. The uneven growth from seasonal variation is recorded as rings that can be seen in a slice through the trunk. The dark bands are dense tissue and represent fall and winter seasons when the tree grew slowly. The light bands are less dense wood and represent spring and summer seasons with more rainfall and sunlight; therefore, the tree grew faster. The trees get thicker as they build layers, with the oldest ring being at the center and the youngest being underneath the bark.

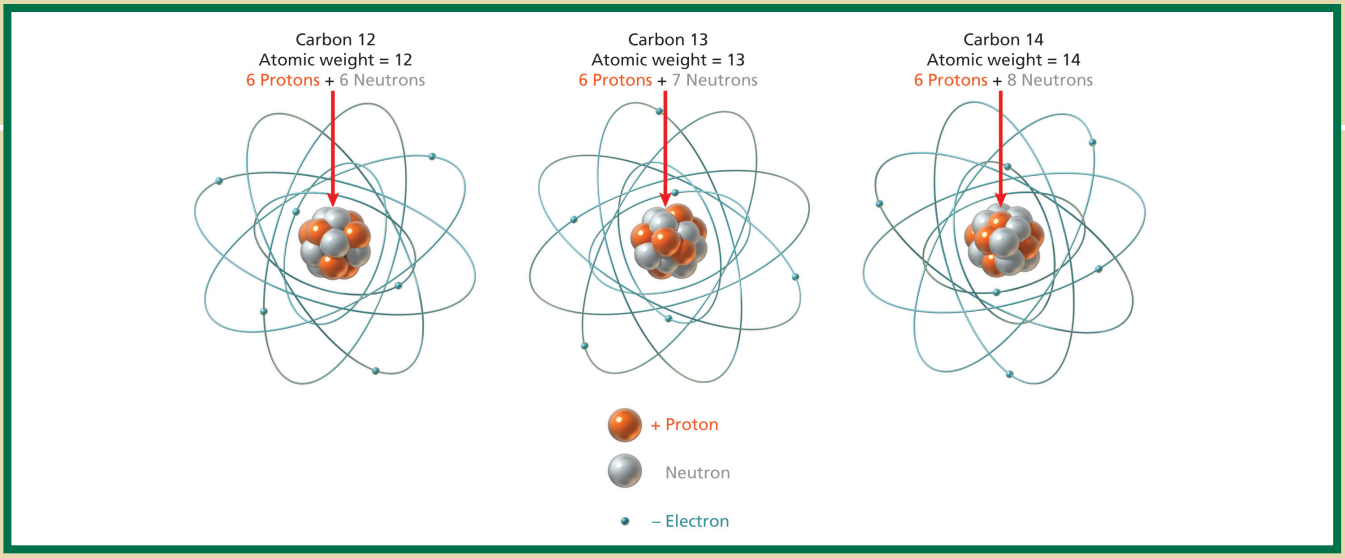
There are many ways to obtain tree slices. Contact your local Department of Natural Resources or a local park-ranger office to find out what materials are available in your area.

How Are Tree Rings Used in Science?

Because a pair of thick and thin tree rings represents one annual climate cycle, scientists can use tree rings to study variables such as seasonal rainfall for periods before people kept weather records. This branch of science is called **dendrochronology.** The thickness of tree rings can be affected by temperature, rainfall, availability of sunlight, carbon dioxide, soil pH, wind, cloud cover, and nutrition. Therefore, scientists can use tree rings to reconstruct past climates. For example, bristlecone pine trees can live for thousands of years, so their rings can provide information about the atmospheric conditions in the locations where they grew. Scientists can sample trees using a small core drilled from a living tree. They will drill cores from several trees in a region to remove any data patterns specific to one tree and to calculate an average thickness of each annual ring.

How Can Tree Rings Be Used to Study Climate Change?

During photosynthesis, sunlight drives a reaction in the leaves of trees between the carbon dioxide (CO_2) in the atmosphere and water absorbed from the roots and air. The result is sugar that a tree uses to build its rings. Therefore, the carbon that was taken into a tree at a particular time becomes captured in the cells of the tree. This can give us information about the atmospheric gases at the time that a particular tree ring formed. Most of the carbon in our atmosphere is ^{12}C, meaning it has six protons and six neutrons. Approximately 1 percent of the carbon in our atmosphere is ^{13}C, which is an isotope of carbon that has six protons and seven neutrons. You may also have heard of ^{14}C, which is an isotope containing six protons and eight neutrons and is used in radiometric dating. Trees and other vegetation tend to absorb more of the ^{12}C atoms from the atmosphere than the ^{13}C atoms. Therefore, for any particular tree ring, we can expect that the ratio of ^{13}C to ^{12}C will be lower than the atmosphere (Real Climate 2004).



Because plants and trees have a lower $^{13}C/^{12}C$ ratio than the atmosphere, it would make sense that fossil fuels (from consolidated plants and trees) would also contain carbon with a similar $^{13}C/^{12}C$ ratio. Knowing the common ratios of carbon isotopes in different substances allows us to determine that carbon dioxide that is currently entering the atmosphere is coming from the burning of fossil fuels. Scientists have used the carbon stored in tree rings to observe historical levels of $^{13}C/^{12}C$ in the atmosphere.

Another application of the carbon-isotope analyses performed on tree rings is to better understand the potential impact of carbon dioxide on climate change. Carbon dioxide records from ice cores show that the atmosphere had greater concentrations of CO_2 when Earth's atmosphere was warmer (during interglacial times) than when it was colder. Scientists have determined that the $^{13}C/^{12}C$ ratio increased 0.03 percent during the transition from the last glacial period to the interglacial period, which took thousands of years. This is significantly less than the 0.15 percent increase in the $^{13}C/^{12}C$ ratio that has taken place in the last hundred years. The concern is that because CO_2 concentration in the atmosphere directly correlates to the temperature of past climates, this tremendous increase in CO_2 will lead to significant warming of the atmosphere.

What Are the Limitations of Using Tree-Ring Data?

The limitations of this research tool are related to the limitations of where trees grow, the types of trees available (some trees do not form annual rings), and their sensitivity to climate conditions. We cannot analyze tree-ring data from mountainous, polar, or water-covered regions where trees do not grow. Because the thickness of a tree ring depends most significantly upon the amount of rainfall for the season, this tool is best used in regions where there are seasonal variations. In mid-latitude temperate zones, the trees will not show winter growth, but data from other seasons can be gathered. In tropical humid regions such as the Equator, the trees grow year-round because there are no significant seasonal changes in sunlight, temperature, or humidity. As a result, this technique cannot be used to collect data about climate change at the Equator.

Pictures of Practice

Evidence of Past Climate Change

Teaching about how scientists study climate and past climate change provides not only a better understanding of science content, but also gives students a glimpse of how scientists conduct their work. Studying climate change involves careful measurements in the field and collecting data that will be used to estimate past climate. Students should learn why scientists study ice cores and tree rings, the elements or molecules scientists look for, and why these are important markers of changing climates.

Students: Grade 8

Location: San Marcos, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss gases trapped in ice and to listen to what students do and do not understand when learning about this phenomenon.

Classroom Context

Ms. Brice's eighth-grade students learn a lot about scientific study in their classroom. Over the years, Ms. Brice has developed many connections to scientists that live both near and far from their school. Ms. Brice incorporates the work of scientists into her instruction, discussing not only their findings, but also the methods they used to collect their data. Her students tour research vessels at Scripps Institution of Oceanography, talk with the captains and crew on the ships, and participate in Skype conferences with Scripps scientists. The lesson in the video appeared in the middle of her unit on climate change, the day before students would participate in video-conferencing with a Scripps scientist.

Video Analysis

In this video, Ms. Brice previews ice-core research with her students to prepare them for a Skype conference with a Scripps scientist the next day. Ms. Brice uses ice from an ice sheet in Antarctica that was collected for her on one of the Scripps research trips, and she has informed her students that they are observing ice dated to be at least 10,000 years old. The point of showing students the ice was to teach them about gases trapped in the ice. When scientists study ice cores they look for oxygen isotopes, which are indicators of atmospheric temperature, as well as trace gases such as carbon dioxide. To begin, Ms. Brice shows her students images of ice layers so that they see that ice has layers similar to what they have seen in tree rings. Next, Ms. Brice capitalizes on her students' experience with carbonated beverages, having them listen to the crackling noises that are emitted when the carbonated ice is dropped in a beaker of water. At the end of the video, Marc is able to describe the *fizz* sound he heard as gases in the ice but does not identify any specific gases or how it is used as proxy data for past climate history.

Reflect

How would you teach about records of past climate change?

This lesson gave students a basic understanding that gases get trapped in ice and that they form layers over time. What would be your next step in teaching about ice cores? What concepts would you focus on in your instruction? How would you improve on Marc's understanding of these gases and why scientists study them?

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Teaching Resources

California Education and the Environment Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm.

Greenland Ice Sheet Project 2: http://www.ncdc.noaa.gov/paleo/icecore/greenland/greenland.html.

Review Article about Ice Cores: http://www.csa.com/discoveryguides/icecore/review.php.

NOAA's Climate Service website: http://www.climate.gov/#understandingClimate.

NOAA Paleoclimatology: http://www.ncdc.noaa.gov/paleo/globalwarming/howdo.html.

5 Modeling the Impacts of Climate Change

by Tara G. Treiber

Models help us understand the universe. They help us imagine things that are too big, too small, too fast, or too slow for us to see directly. Models are representations of phenomena and other concepts.

Most students are familiar with simple models, such as one they might make of our solar system with coat hangers and Styrofoam balls. Such a model helps people envision events that happen on a size or time scale that they cannot easily see. When the planets and sun of such a model are all properly arranged as they are in space, students can view how they move; they can also view how they might be aligned in the future. The more accurate the initial data that goes into a model, the more accurate its predictions of the future will be.

Scientists often use computer-based models to help them understand what is happening right now, as well as what might happen in the future. When all the pieces of a model are put together, the model can run forward in time to see what the future might look like or backward in time to understand the past.

Computer models of Earth's global climate system are complex. They include many data points that represent parameters that intersect and interact with one another. They include events that take place on different scales of time and space. They also include many phenomena that scientists are still struggling to make sense of, such as cloud and hurricane formation. Because of their complexity, many climate models are actually simulations in which multiple changing factors demonstrate, or "model," how climate has changed and continues to change over time.

Students may wonder how scientists make predictions about rising temperatures or sea levels, so talking about climate models is necessary for their understanding. Most climate models today are created and run on high-performance computers capable of processing the millions of equations that represent factors that affect global climate. One major climate-change model built by Oxford University was set

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.2 3.5.1-3 3.3.a-b 3.3.c-e	The Geography of Where We Live California's Economy—Natural Choices Structures of Survival in a Healthy Ecosystem Living Things in Changing Environments
Grade 4	4.1.3 4.3.b 4.6	Reflections of Where We Live
Grade 5	5.3.d-e 5.6	Our Water: Sources and Uses
Grade 6	6.2.2 6.2.c 6.5.e 6.7	Agricultural Advances in Ancient Civilizations
Grade 7	7.3.a 7.3.e 7.7	Shaping Natural Systems Through Evolution Responding to Environmental Change
Grade 8	8.12.1 8.12.5 8.9	Agricultural and Industrial Development in U.S. Industrialization, Urbanization, & Conservation

up to run using the personal computers of volunteers—more than 90,000 computers in total! This number demonstrates how much computational work is involved in running climate models.

A model is only as good as the data used in its construction. Students know that it is important to take careful and accurate measurements in lab experiments. Think about how important this accuracy is for using data in climate models.

Scientists often check to make sure that our knowledge of climate is accurate by looking into the past. They create models using data that represent conditions for a particular time range and then run the model to see if it can recreate the conditions known to have occurred in the past. If it does, the model is considered valid, and the scientists have confidence that they can use that model to predict what might happen in the future.

CHAPTER OVERVIEW

Climate science can be difficult to understand because scientists are studying and trying to make sense of large-scale, complex systems across long periods. Scientists use models to help them better understand these systems. Climate models that account for many variables and are based on data obtained through careful and accurate measurement are more likely to produce accurate models of what is currently happening, as well as predictions of future impacts.

The climate models today tell us that our Earth systems are going to experience notable impacts from climate change. The ocean is warming and changing in chemistry, which alters the habitats for many marine organisms. Ice in our polar regions and high alpine glaciers are melting fast, reducing habitats for polar and alpine organisms and contributing to sea level rise. Less freshwater is available during spring melts, and precipitation patterns are changing around the world. Not only will humans need to adapt to these changing conditions, but also all living things must find a way to survive or they may perish.

In this chapter we explore how scientists use climate models and then take a closer look at what these models tell us about impacts on our Earth's systems.

Where do data from the past come from? The answer depends upon the period being explored. If we look at the last 200 years or so, we have very accurate written records of weather parameters such as temperature, precipitation amounts, and number of cloudy or sunny days recorded for a good percentage of Earth's surface.

If the period of interest is over the past 4,000 years or so, scientists can look at anthropological data—everything from birth and death lists, farming records, and the writing of a time, to the evidence of diet, food sources, and tools used during a specific era. These things all can tell us a great deal about what occurred in past civilizations.

When looking even further into the past for evidence of climatological trends, scientists primarily look at natural records including ice cores, tree cores, and coral bands for information about weather events and climate, as discussed in Chapter 4. As trees and coral grow, they incorporate gases from the atmosphere or the ocean, respectively. Some trees and corals have been around for thousands of years, so their annual rings or bands can give us an accurate picture of the atmosphere or ocean for that time frame. When taken all together, these data can be used to create a picture of the climate conditions at a time and place in the past. The more bits of data that can be compiled, the more accurate the models of our past can be.

Once scientists have a good understanding of the past and the present climate, as well as all the factors that influence climate conditions, they can generate computer code to represent the processes as mathematical equations. To examine how a change in current conditions would play out in the future, they can change the variables and run the model to see the results. By adjusting the model's input values, they can add more CO_2 to the model atmosphere or diminish its ozone layer. They can alter any number of variables that may affect how Earth's climate will function in the future. Then they can run their model to see the results.

Scientists collect coral cores from a coral skeleton. The coral skeleton shows different densities based on seasonal and environmental changes over time, so scientists can study how the environment around the coral has changed in the past.

One phenomenon climate modelers need to take into account when building a model is the processes of **feedback loops.** Feedback loops can be positive, thereby magnifying or accelerating an effect, or negative, which reduce an effect. For example, the albedo effect of ice leads to a positive feedback loop. As ice melts on our planet, there is less sunlight being reflected and more of the sun's energy is being absorbed. As the energy is absorbed, the surface warms faster, leading to more ice melt. As more ice melts, even more energy is absorbed. While feedback loops are complex, students can understand the key ideas about feedback loops and simple examples.

An example of a negative feedback loop that has been explored by scientists is that of plant growth. Some plants and algae, including phytoplankton, grow faster in conditions of higher carbon-dioxide concentrations. As they photosynthesize and grow, they remove carbon dioxide from the atmosphere and use it to build their carbon-based tissues. As their growth lowers the concentration of carbon dioxide in the atmosphere, they can't grow as efficiently as they did at higher CO_2 levels, so the effect of high CO_2 concentration is reduced.

Clouds and aerosols represent challenges in global climate-change modeling, because they can have a positive feedback effect on heating by trapping radiation between them and the surface of Earth, but they can also have a negative feedback effect on heating by reflecting the sun's radiation back to space before it ever reaches Earth's surface. As the effects of some climate parameters are not known precisely and so much new information is learned each year, it is easy to see why results from climate modeling seem to change frequently. However, scientists know global climate change is happening, and they are using their best models to predict how Earth might look in the future. Let's explore some of these predictions.

Case Study

The Ocean in a Changing Climate

The majority of Earth's surface is covered by water, specifically ocean water. Because human activities began increasing the concentration of atmospheric carbon dioxide at the beginning of the Industrial Revolution, the ocean has been absorbing it. Scientists estimate that the ocean has absorbed about 30 percent of the human-emitted CO_2 released in modern times. While the ocean is able to absorb a great deal of CO_2 as well as excess heat, it too has its limits. The ocean is, by and large, a relatively cool part of our planet. Additionally, because water has high specific heat (which means it takes a lot of energy to raise the temperature of water even a slight amount), the ocean is slow to warm.

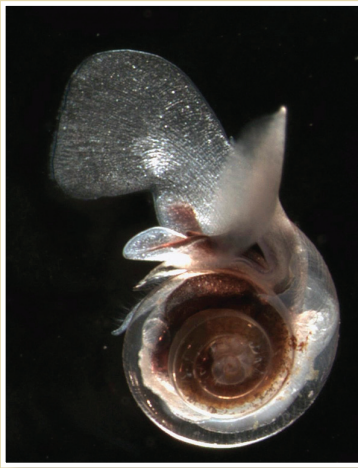
Overall, scientists have detected an increase of 1.3°F (0.74°C) in global average temperature over the past century. However, during this time, the ocean has only warmed an average of 0.5°F (0.28°C), with greater warming at the Poles than at the Equator. Changing ocean temperatures may result in an array of changes to our planet, including modifications of global ocean currents. As currents and temperature patterns of the ocean change, so do the migration routes of animals and the range and distribution patterns of plant and animal species.

Ocean Acidification

Though we can see carbon dioxide as bubbles in a soda, this gas is invisible in the air around us. The ocean, which is in constant contact with the atmosphere and physically mixes with it, especially where waves break, absorbs a great deal of carbon dioxide from the atmosphere.

The conversion of carbon dioxide into oxygen by photosynthetic organisms such as algae and phytoplankton is part of the reason our atmosphere is able to support life. Some scientists estimate that as much as 70 percent of the oxygen in our atmosphere was released to the atmosphere through photosynthesis as algae and phytoplankton incorporated carbon dioxide into their structures. Therefore, carbon dioxide's presence in the ocean is not only natural, but also important to all life on Earth. However, the recent increase in carbon dioxide in the atmosphere has changed the amount of carbon dioxide in the ocean, increasing the acidity of the ocean as the CO_2 reacts with other components of the water.

In addition to photosynthesis, marine organisms use carbon dioxide to form their skeletons and shells. The mineral name for their shell material is carbonate. Marine life—from corals to scallops and snails to shrimp—all build carbonate structures from materials within ocean water. As the ocean becomes more acidic, these shell-building organisms are less able to accumulate carbonate for their structures. This environmental change can ultimately threaten their survival.



***Limacina helicina* (sea butterflies)**

Ocean acidification and its impacts are not something that scientists are predicting will occur in the future: ocean acidification is occurring now. In some areas, the ocean's pH (measure of acidity) has increased by about 30 percent or more since the onset of the Industrial Revolution. Indeed, some species are already being affected by this increased acidity. For example, oyster farms in Oregon have been experiencing larval die-offs, and all evidence points toward ocean acidification as one of the culprits.

Scientists are using models to estimate possible long-term impacts of ocean acidification. Model projections estimate that ocean acidification will directly impact the availability of commercially produced shellfish in the next several decades. This means fewer shrimp, lobster, clams, and other shellfish will be available to people for food. In turn, the demise of commercial fisheries could have a negative economic impact in coastal communities worldwide. Studies suggest that it is not unreasonable to expect an annual loss of $10 billion per year due to loss of shoreline protection and reef-supported fisheries as a result of ocean acidification. Also, as a large percentage of the world's population depends upon the ocean for its source of protein, the lack of shellfish could result in greater levels of malnutrition or starvation in many parts of the world. These are only the direct impacts. The indirect impact to the ocean food chain could be more insidious and far-reaching. Models show that planktonic species such as coccolithophores and pteropods, organisms at the base of the ocean food chain, will have trouble forming their shells, without which they cannot survive or reproduce. If the base of the marine food chain collapses, all species connected to it could disappear, or, at the very least, suffer massive population reductions. Research on some other species shows that decreased pH has little-to-no impact on their shell formation. As a result, scientists are still debating and researching what ocean acidification will mean for the future health of the ocean and humanity. This important new area of research will need many new scientists to study the issues and propose solutions.

Warming Oceans.

As Earth's atmosphere warms, the surface temperatures of the ocean are warming. In turn, the warming water melts icebergs, ice shelves, and glacial ice. As ice on land melts and runs into the sea, and water in the ocean expands as it warms, global sea-level rises. Though different stretches of land are slowly rising or subsiding along coastlines around the world, overall, satellites have detected that global sea level is rising.

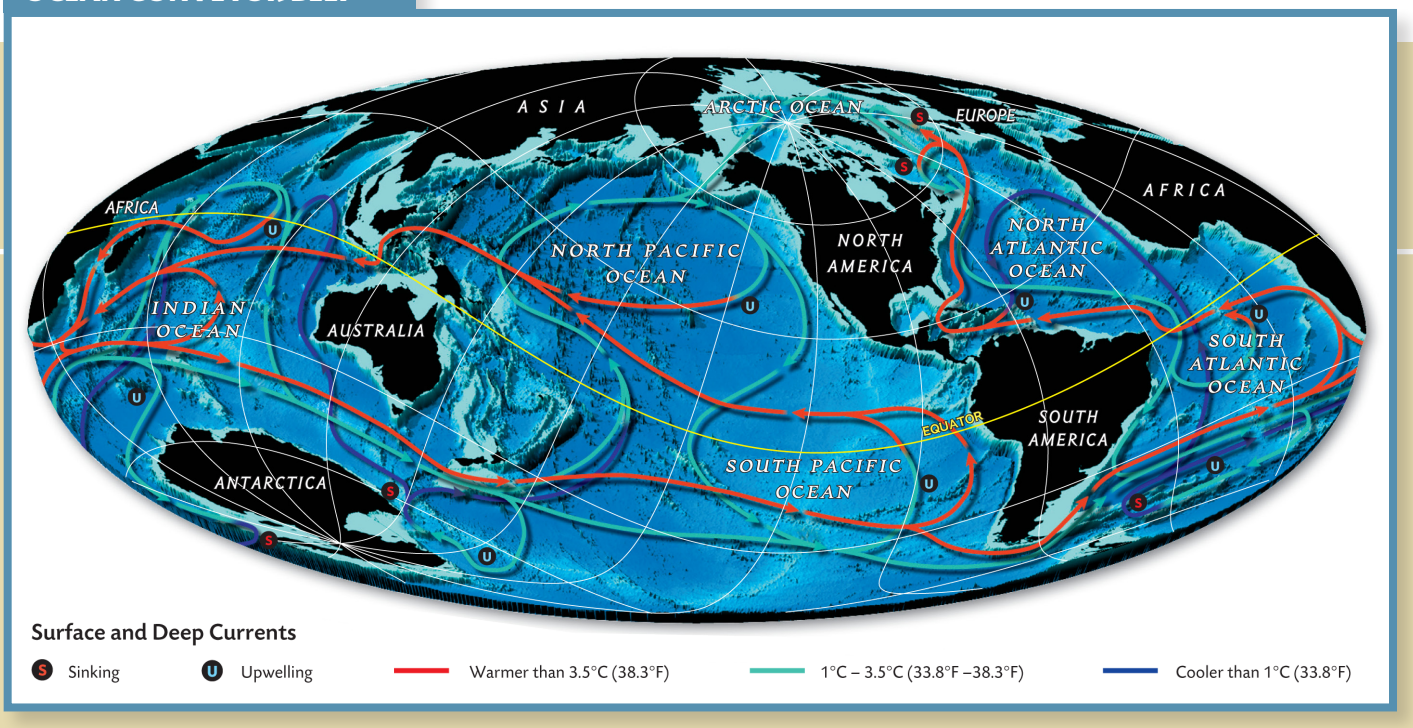
More than a third of the world's population lives within 60 miles of the ocean.

More than one-third of the world's population lives within 60 miles of the ocean (NASA 2010), so rising sea level could have a huge impact on human settlements and has already affected some Arctic and island communities. Models of sea-level rise are based on estimates of how much the ocean is expected to warm at different depths and how quickly existing glaciers and ice sheets might melt. However, this area of climate science and modeling is not yet very mature, and estimates for sea-level rise range widely. We do know that higher waters will increase the amount of coastal erosion that occurs over time, which contributes to the loss of land due to wind and waves. In California, the coastline is one of the state's most valuable resources, and coastal erosion could result in a loss of as much as $1.4 billion in lost real-estate values each year. Take a look at Scripp's Then and Now maps online at http://coastalchange.ucsd.edu/st1_thenandnow/index.html.

Teaching Tip

A simple way to demonstrate how water can absorb carbon dioxide is to have students exhale repeatedly through a straw into a lidded cup of water. Have them check the pH of the water before they begin blowing and then again after 2—3 minutes, and again after 5—6 minutes. Have them see how quickly they are able to change the pH of their water. To demonstrate the relationship between acidity and its ability to dissolve chalk, you can use cups or beakers of water at varying acidities (this can be accomplished by blowing into the cups as previously shown or by adding vinegar), and placing a small piece of chalk or a small shell into each cup. Have students record how quickly or slowly the chalk dissolves at each pH level. (Note: To ensure proper hygiene, have each student use a separate straw to blow into the cups).

OCEAN CONVEYOR BELT



The ocean is in constant motion, driven by surface winds and controlled by water temperature and density. Great landmasses guide the direction of water movement, creating an enormous conveyor-belt effect.

Ocean Circulation.

Along with global winds and our planet's rotation, ocean circulation is driven by differences in the density of its waters. The density of any volume of ocean water depends upon how much salt is dissolved in it (a measure called **salinity**) and its temperature. Freshwater, which contains only a trace of dissolved minerals, is less dense than salt water. Water with a higher salinity (greater saltiness) or colder temperature is denser than water with a lower salinity (less saltiness) or warmer temperature. Dense water tends to sink below water that is less dense, and this helps to move ocean water around our planet.

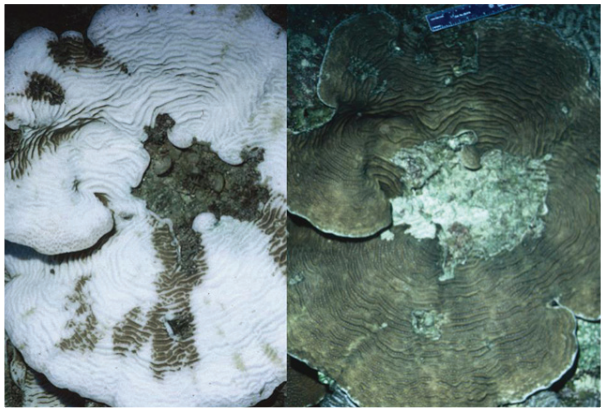
Scientists refer to the continuous stream of water circulating throughout the ocean basins as the **ocean conveyor belt.** In the Atlantic Basin, as water warms at the Equator, it evaporates, leaving saltier water behind. This water moves north along the east coast of North America in the Gulf Stream. The cooler Arctic air in the North Atlantic then chills the salty water. This water, now being colder and saltier and, therefore, denser, sinks—driving water back toward the Equator where the process starts over. Similar processes also occur in the Pacific and Indian Oceans, moving water through all the ocean basins.

When ice on Greenland melts, freshwater runs into the ocean. Scientists are worried about the impact of this melting ice adding low-density freshwater to the North Atlantic in the location where salty water normally sinks. Scientists are watching for signs that this process might slow the ocean conveyor belt. Because ocean currents have a large influence on climate patterns around the world, a slowing of the ocean conveyor belt could have major impacts on global weather and temperature patterns.

Impacts on Ocean Biodiversity.

Like plants and animals on land, marine organisms all have a specific range of conditions in which they can live. Changes in temperature, salinity, currents, and pH (ocean acidification) are changing where species can thrive and survive. Some organisms, such as plankton, are being found in new locations where they were not found in the past. Such changes in plankton distribution and abundances can impact the entire food chain. Even whales are not immune to the influence of global climate change. Whether changes in their distribution are due to changing currents and ocean temperatures or changing patterns of food availability (or some other cause, not yet discovered) is unknown, but migration patterns of Pacific gray whales and blue whales seem to be changing.

Gray whales are leaving Arctic waters later than usual for their long haul to the warm waters off Baja California, and



In water warmer than 86˚F (30˚C), corals expel their algae, which causes them to look white. This is known as coral bleaching.

returning to the Arctic later as well. Scientists who study gray whales are accumulating evidence that seems to indicate that the whales are not able to find enough food in the formerly food-rich, Arctic waters. Additionally, aerial photography shows the whales may be thinner than usual as they are returning to Baja California. Migration patterns of blue whales, the largest creatures on Earth, seem to be changing as well: They may be increasing their range in search for food. These data are all preliminary and not well explored. Adding further uncertainty to the conclusions is that whales were hunted almost to extinction in the last century, and they were not well studied before their huge population declines. It could be that they are re-establishing former migration patterns or responding to more local environmental events. The issue of the impact of global climate change on the great whales is also the tale for many other species; we didn't learn enough about them before global climate change began to impact the planet, so it is difficult to interpret if or how they have been affected by current conditions.

One type of organism that could be viewed as a "canary in the coal mine" for global change is reef-building coral. Scientists have been documenting the decline of coral reefs worldwide for several decades. While corals are stressed by a number of factors, including pollution, overfishing, and unsustainable fishing methods, the warming ocean is now the biggest survival challenge they face. Many corals contain microscopic algae that give the coral their color and provide food (sugars) for the coral through photosynthesis. When ocean water becomes too warm, however, corals sometimes expel their algae. Loss of the algae leaves the coral looking white, hence the term **coral bleaching.** Without the sugars from the algae, corals don't receive as much food, and they can die.

Bleaching is not the only risk related to climate change for coral reefs. Rising ocean temperatures may also enable or encourage the growth of bacteria and viruses that can adversely affect reef health. In an increasingly acidic ocean, models also predict that corals will have trouble getting enough calcium carbonate from sea water to grow their skeletons. Additionally, as Earth's ice melts and sea levels rise, the corals may be covered by too much water to survive. Models show that an ocean temperature increase of 3.6˚F (2˚C), is enough to wipe out the world's coral reefs, if they cannot adapt to changing conditions. As 25 percent of all marine species are estimated to spend some part of their life in a coral reef (especially while they are young and vulnerable to predators), the loss of reefs could have devastating impacts to the ocean food web, fish populations, and ocean-based foods caught around the world.

Not all ocean species are being negatively affected by global climate change. One marine species that seems to be benefitting from climate change is the Humboldt squid. Once rare north of San Diego, this species is now sighted regularly as far north as Alaska. Preliminary studies indicate that the Humboldt squid may be taking advantage of warming waters associated with global climate change, as they have a relatively low tolerance for cold waters.

The range of the Humboldt squid may be changing as our ocean warms, thus benefiting from changing climate conditions. To learn more about the Humboldt squid, See lesson 1 in http://www.calepa.ca.gov/Education/EEI/Curriculum/Grade04/42b/42bSW.pdf.

Student Thinking

Climate and the Ocean

Students' understanding of global climate change as it relates to the ocean is tightly coupled with their understanding of the ocean itself. While students are often excited and engaged when learning about the ocean, they can still harbor misconceptions and misunderstandings about the ocean that can hinder their ability to grasp what the ocean has to do with global climate change.

	Common Student Ideas	Scientific Concept
Temperature	The ocean is already a warm place so global climate change is going to lead to it becoming really hot, maybe even boiling.	When students go swimming at the ocean, they usually stay in warm near-shore areas, but the majority of the ocean is relatively cold. If global climate change warms the ocean by just a few degrees, marine life will experience major disruptions.
Biodiversity	If global climate change happens, all the animals in the ocean will die.	Studies are already showing that some species will thrive under the new conditions, especially gelatinous animals.
Currents	Currents will be the same; they'll just be warmer.	Many currents are driven by temperature, salinity, and density differences. A changing climate can alter all of these, thereby altering the currents.
Migration	Animals can just move someplace new if the ocean gets too hot or there isn't enough food.	Some ocean animals are capable of migrating to new ranges but not all of them. Some animals are sedentary (don't move) as adults. It might take those species a while to adjust, as their larva are the ones helping to expand their range.
Adaptation	Animals can just get used to changing conditions, or they will evolve to be able to survive.	Adaptation and evolution do not happen in a single generation, neither are they guaranteed to occur just because the environmental conditions change. Organisms need to have the genes for advantageous characteristics in order to survive changing conditions.

Ask Your Students

1. What could happen to marine life if the ocean environment changes? Why do you think this may happen?
2. If cold, dense freshwater enters the ocean from melting polar ice, how could this change our ocean currents?
3. How long does it take for an organism to adapt to changes in the ocean environment?

Please see "One Ocean: A Guide to Teaching the Ocean in Grades 3 to 8" for more information about student understanding of the ocean.

Case Study

Melting Ice on Earth

Warming oceans and air temperatures are causing ice on Earth to melt. The impact is being felt at the Poles more than in any other location. When one looks at a globe, the Poles are easily distinguished by the white color that represents the ice and snow found in these locations. However, the average amount of ice and snow has been reduced over the past few decades. Most of the ice in the Arctic is present as sea ice, ice shelves (ice attached to the land and jutting out to sea), glaciers, and in Greenland's ice sheet. The continent of Antarctica has even more ice: it is covered by a thick ice sheet and has several large ice shelves.

Northern Ice

In winter, ever since humans began monitoring it, the surface of the Arctic sea has developed a covering of ice from the north edge of North America to the north edge of Europe and Asia. This ice is very similar to the ice that forms on freshwater lakes and ponds during cold winters in other parts of the world. Every summer, this ice melts back a bit. The area teams with life at this time, with animals swimming through and using remaining chunks of floating ice as platforms for resting or hunting. During this time, ships also move through the region to avoid taking a longer trip around continents.

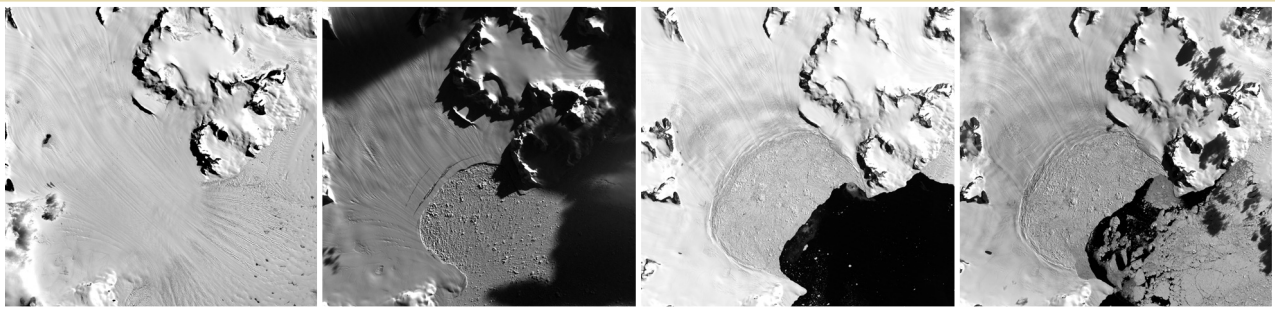
Arctic sea ice reaches its maximum area, or extent, at the end of winter, generally during March of each year. After melting through the summer months, it reaches its minimum extent in September. Since 1979, when satellite coverage first allowed scientists to measure the area covered by ice, the September minimum has been reduced by at least 10 percent per decade. Year-to-year fluctuations in sea ice extent depend on weather systems over the Arctic. However, the long-term trend of decreasing ice may indicate that global climate is warming. Models predict that the Arctic could become essentially ice-free during the summer within a few decades.

Ice on land has also been disappearing from the Arctic. Warming temperatures are causing the melt of glaciers in the Arctic and at lower latitudes, including glaciers throughout Alaska, Colorado, Montana, and other U.S. states. Some scientists estimate that the glaciers of Glacier National Park, a place so unique and precious it was given protection by the National Park Service, could mostly be gone as early as 2020.

Many species depend on Arctic sea ice for their survival. One species whose reliance upon sea ice has made them important symbols of global climate change is the polar bear. The polar bear uses sea ice as a platform for hunting and migration, and the snowpack on land for building dens and raising their young. A lack of sea ice may lead to polar bears having difficulty locating food, underfed mothers giving birth to lower weight babies, and an inability to reach birthing dens. These factors put the continued survival of polar bears at risk: Some scientists estimate that two-thirds of all polar bears could be gone by 2050 if current trends continue. On the other hand, there are several different populations of polar bears, and some are less susceptible to global climate-change impacts than others. Walrus and narwhals are two other species whose reliance upon sea ice also puts them at risk for extreme population losses as Arctic sea ice decreases.

Greenland Ice

Greenland is covered by an ice sheet that is thousands of feet thick. Radar measurements that can "look" through the ice show that the land below the ice is a high plain, ringed by coastal mountains. Over the past 15 years, the average winter temperature of Greenland has increased by 11°F (6° C). As the surface of the ice sheet begins to melt at these warmer temperatures, water flows across the surface and into the sea or melts its way down to bedrock and acts as a lubricant, enabling ice to slide downhill toward the sea. All the water and ice that flows off of Greenland contribute to global sea-level rise. Should the entire Greenland Ice Sheet melt, models predict that global sea level will rise 23 feet (7 meters).



These NASA Landsat images show the break up of the Larsen B ice shelf. Images were taken from January 2000 to February 2002 (chronologically left to right).

Antarctic Ice

The majority of the southern polar region, the Antarctic, is frozen. Unlike the Arctic, however, the Antarctic has a base of land—the continent of Antarctica. Antarctica is covered with ice, divided by a mountain range into two separate ice sheets—the East Antarctica Ice Sheet and the West Antarctica Ice Sheet. The continent is surrounded by sea ice that expands dramatically during the Southern Hemisphere's winter, then melts back again when spring arrives. The ice on Antarctica holds 70 percent of the planet's freshwater. The East Antarctica Ice Sheet covers the continent with ice that is up to 2.5 miles (4 kilometers) thick. In the unlikely event that the East Antarctica Ice Sheet would melt, it would raise sea level by more than 160 feet (50 meters)! The West Antarctica Ice Sheet is actually resting upon the rocky bottom of what was once a shallow sea basin. Scientists predict that if it should melt, it would raise sea level approximately 20 feet (6 meters).

Ice shelves and sea ice surround the continent. The ice shelves are often so thick it is difficult to differentiate them from ice that is on the land. Satellite images of one ice shelf, known as Larsen B, showed that the ice was breaking apart into icebergs. Scientists thought the complete breakdown of the shelf would take years, so they were shocked to see that it broke up over a matter of weeks beginning in February of 2002. Scientists determined that Larsen B had been riddled with cracks and crevasses, as well as melting from below. As Larsen B broke up, scientists also became aware of the important role this ice shelf was serving: It was acting as a dam, holding back neighboring glaciers and keeping them from creeping ever closer to the ocean. Without the ice shelf, glacial ice was measured to be moving toward the sea eight times faster than before!

Melting Permafrost

A unique ecosystem is found in the Arctic, known as the Arctic tundra. Low-growing mosses, lichens, and shrubs, as well as frozen layers of soil called **permafrost,** characterize this ecosystem. Permafrost is just like it sounds—permanent frost or a permanent frozen condition of the ground or at least frozen solid for two years at a time. In the summer, the surface soil often thaws, but the deeper layers of soil remain frozen year-round.

The roads and buildings erected on the tundra of Canada, Russia, and Alaska were engineered to sit upon this permafrost. As the planet warms, however, the permafrost is thawing. As the permafrost melts, the structural integrity of buildings and roads are at risk. Scientists, engineers, and government officials are concerned that the melting permafrost could lead to the collapse of buildings and breakdown of roads and highways, as well as damage runways and sewer and water pipes. Additionally, the Trans-Alaska Pipeline that carries petroleum drilled from the North Slope of Alaska is at risk because its base sits upon permafrost. Another risk with loss of permafrost is erosion. Frozen soils are resistant to coastal erosion, but when they thaw and become softer, more of the Arctic coast may be washed away.

The Arctic tundra is home to a variety of plants and animals specifically adapted to this habitat. As the tundra warms, the forests of the Northern Hemisphere are able to grow north of their former range. As the tundra disappears, so does the habitat of many animals such as the caribou. Birds also visit this area during the spring and summer to nest and eat in the insect-rich region. Melting permafrost and disappearing tundra could have major implications for hundreds of species and their food webs.

Student Thinking

Ice and Climate Change

Understanding life at the Poles can be challenging for students. Few will ever see the Arctic or Antarctica, and popular media is often full of confusing imagery about these far away places. Additionally, when it comes to understanding global climate change and its effect on these habitats, students can become easily overwhelmed by the thought of losing something they have never seen. When teaching about the polar regions, you can help students by focusing on prior knowledge using a KWL (Know, Want to Know, Learned) Chart or a Venn Diagram to compare the polar regions.

	Common Student Ideas	Scientific Concept
Life at the Poles	Polar bears are dying because they can't find enough food to eat, like penguins. Both polar bears and penguins live in the same area.	Polar bears are found only in the Northern Hemisphere; penguins are found in the Southern Hemisphere (note that one species of penguin is found in the Northern Hemisphere on the Galapagos Islands, which is near the equator). Both penguin and polar-bear populations will be affected by global climate change, but the two animals are not directly linked.
North Pole	The North Pole will disappear if the sea ice all melts.	There is no land at the North Pole, only ocean that is currently covered by floating ice. The North Pole is defined by the movement of Earth and its axis of rotation and will still be the North Pole even if the ice melts.
Global Ice	When the water warms up the ice all melts.	As the ocean's temperature warms, some of the ice will melt, but not evenly.
Melting Ice	When ice melts, sea level in the ocean will rise.	Sea ice melting in the Arctic Ocean Basin will have minimal effect on sea level rise compared to melting ice sheets on Greenland and Antarctica, which will have significant influence on sea level rise.

Ask Your Students

1. Can you find polar bears and penguins in the same habitat?
2. If all the ice melts in the North Pole, will the North Pole be gone? Why or why not?
3. Will melting ice from Antarctica affect the ocean the same as melting ice from the Arctic?

Pictures of Practice

Melting Ice

Students have likely heard about melting polar ice and threats to polar wildlife caused by climate change. In the last decade, we have witnessed unprecedented melting of our polar ice. Data from NASA scientists show that Arctic sea ice has decreased substantially from the long-term average, and Antarctica is also losing ice mass in certain regions, although there is more uncertainty about Antarctic melting compared to Arctic melting (for more information visit http://climate.nasa.gov/). Students may have questions about what will happen as this ice melts and enters other systems on Earth.

Students: Grade 8

Location: San Marcos, California (a coastal community)

Goal of Video: The purpose of watching this video is to listen to student ideas about melting ice in different polar regions and outcomes of melting ice on the ocean and climate.

Classroom Context

Ms. Brice taught an extensive unit on climate change to her eighth-grade students; content especially focused on current research on changes in the ocean system. This lesson was the first in the unit on melting polar ice. The interviews occurred only two days after the lesson.

Video Analysis

In this video students are wrestling with possible outcomes of melting polar ice. As polar ice caps melt, scientists are concerned with outcomes of cold, freshwater entering our ocean and how this will impact sea level and ocean currents. Ice in the arctic is mostly sea ice (save the massive ice sheet covering Greenland). The ice in Antarctica is mostly covering land. The melting of ice on land will influence sea level far more than melting sea ice, which will have little to no impact on sea level.. But the melting of sea ice in the Arctic has another disturbing consequence—the potential to change, or halt, our ocean currents as dense, cold, freshwater enters our northern ocean (read more at http://science.nasa.gov/science-news/science-at-nasa/2004/05mar_arctic/). Changing water temperature, chemistry, and density from melting polar ice may impact our ocean currents, which could also affect the movement of air masses, especially in the northern Atlantic. In this video, Ms. Brice teaches about the difference between melting sea ice in the Arctic compared to melting ice sheets on Greenland and Antarctica. The class talks about the percentage of an iceberg that is visible above sea level. After some discussion, the class agrees that the answer is approximately 10 percent. Once the class has understood the concept of sea ice versus ice on land melting, students explain the possible consequences of melting ice in their interviews. The class then discusses what will happen if cold, dense water enters the ocean. Listen as students describe the possibility of another ice age. What did they understand and not understand from the classroom discussions?

Reflect

What would be your next step to teach about melting ice and the ocean system?

What did students seem to understand and not understand during their interviews? What were the most important misconceptions? Given that these students have had some, but limited, discussion on the topic, what additional activities and discussions could you do with students?

Case Study

What About Freshwater?

Some basic physical principles that are incorporated into global climate models are relatively easy to understand. One of these is that warm air can hold more water vapor than cool air. Because warm air can hold more moisture than cool air, the climate along the Equator, where the sun's rays are most direct, tends to be warm and wet. Conversely, climate at the Poles tends to be cold and dry. Following that warm air can hold more moisture than cool air, models predict that increases in air temperature will bring more frequent episodes of heavy precipitation. However, rainfall amounts aren't expected to increase evenly across the planet; instead, models project that most of the areas with traditionally arid climates will become even drier, and areas with wet climates will become wetter. Overall, regions are expected to see increases in extreme weather events such as droughts and floods.

In a warming climate, more and more of the precipitation that falls will arrive as rain instead of snow, especially in the mountain regions. When snow falls in the mountains, it creates a free and easy method of storing water. In the spring and summer, as the snowpack melts, the water runs downhill over time, moving through the watershed where it can be utilized for agriculture, business, and household needs. In many areas, the winter months already see plentiful precipitation, while the spring and summer can be drier. The melting snowpack is an important water source during those times. If precipitation falls as rain instead of snow in these mountain regions, it will flow downstream, and won't be available in later times of need. This problem could be devastating to many states, especially California, where the primary source of water in the state is the snowpack of the Northern Sierras. Southern California already faces water shortage issues—should the snowpack disappear, this situation could worsen. Additionally, the lack of water, combined with warming trends and possible droughts, may also increase the likelihood of a greater number of wildfires.

Agriculture is also at risk from global climate change. Many crops are grown in a particular location due to their need for a particular temperature or rainfall amount. Farmers have determined over time where and when to plant particular species. As rainfall patterns and temperatures change, some crops may not be able to grow in areas where they have been raised in the past. Warming temperatures also favor an increase in insects that can damage crops; these can be difficult to manage without the use of toxic pesticides. Increased carbon dioxide in the atmosphere also seems to encourage the growth of certain classes of plants, most commonly known as weeds. In California, agriculture is a $30 billion industry that directly employs more than one million people and grows more than half of the nation's fruits and vegetables. The agricultural industry will need to be ready to adapt to the consequences of global climate change, or it could experience huge economic impacts that could ripple through the entire U.S. economy.

Pictures of Practice

Surviving Climate Change

When students are asked about who will be affected by climate change, most will mention the polar bear. The polar bear has become the iconic species impacted by climate change. Videos show polar bears swimming for miles between sea ice in order to find food for survival, and students have likely heard stories about declines in polar bear populations. Students are less aware of threats to other species. In fact, they likely know very little about how their own local plant and animal species populations are changing.

Students: Grade 8

Location: San Marcos, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss how organisms will survive or perish in climate change.

Classroom Context

Ms. Brice's students are finishing their unit on climate change and reviewing key concepts during small-group discussions. Each small group will then present a question and their ideas to the whole group for discussion.

Video Analysis

This video examines student ideas about adaptation and survival in changing climates. Although students know that plants and animals are adapted to particular environments, they likely know less about how those species came to be so well-suited to their habitat. The process of evolution describes how a population changes over time through natural selection. A species today is adapted to its environment because the species successfully survived and reproduced over thousands to millions of years. Time span is an important element of plant and animal survival, yet many students (as you see in the video) believe that organisms can choose to change or that changes come naturally within an organism's lifetime. While humans have the ability to survive in many diverse habitats, many plants and animal species are adapted to a specific habitat, and even the smallest of changes influences their ability to reproduce. When the change is slow, a subset of the population can continue to reproduce because they have favorable traits. When the change is abrupt, plants and animals cannot simply adapt because they have the will to do so. Extinction is the result of a species' inability to cope with a changing environment. In the first part of the video, students are interviewed about how climate change will affect life on Earth, and you will hear students mention that animals may struggle to survive. Hailey first asserts that climate change will affect living organisms but is not sure why. During the small-group discussion, students talk about how plants and animals are just born with their adaptations but eventually come to the conclusion that adaptation came through their "ancestors." The discussion ends with the idea that plants and animals will have to adapt quickly to climate change or they will go extinct. Marc proposes that polar bears will need to lose fur to live in warmer climates.

Reflect

How would you respond to student misconceptions about adaptation?

These eighth-grade students seem confused about the time it takes for a population to change with a changing climate. While they seem to understand that organisms today inherit adaptations from ancestors, they also believe that individual organisms can choose to adapt to climate change within short periods. What are the concepts that students do not seem to understand, and what concepts do they mention that would be helpful for them to know? How would you teach these concepts?

Case Study

Species Coping With Change

In each of the previous case studies, we touched upon some species currently being affected by climate change, but there are many others. Animals that are experiencing the most negative effects of climate change are birds, butterflies, and amphibians, especially frogs. Plants are also showing changes that result from increasing global temperatures.

Many species of trees and flowers are coming out of their winter dormant period earlier than in the past, due to warm temperatures arriving earlier in the year. Populations of organisms in food webs that feed on these plants could be affected by this change. Additionally, many species are budding and blooming several days earlier than in the past. While this might not seem like much, their flowers only last for a finite period. In the case of many plants, they may be blooming out of synch with the arrival or maturation of their pollinators, which could have a negative effect on their continued survival.

Additionally, some populations of migratory birds are threatened by the loss of permafrost and Arctic tundra habitat for nesting. Often birds take their migration cues from temperature. As the planet has warmed, warm temperatures come earlier than in the past, and some birds are leaving their winter feeding grounds and returning north at earlier dates. Due to their early return, they are also nesting and laying eggs earlier in the springtime. Scientists are concerned about these earlier migrations and chick-hatching dates; this can put birds out of synch with populations of insects (food for the birds) that take their timing cues for hatching or metamorphosing from the length of day or night. While global climate change is altering a number of systems on our planet, it will not alter the length of our days and nights. The mismatch in timing may reduce the availability of food for birds, ultimately having a negative impact on bird populations.

Warming temperatures disrupt bird migration, nesting, and hatching, potentially putting birds out of synch with the populations of their food sources.

Butterflies are often sensitive to temperature change. Most cannot handle temperature extremes: many of them hibernate, lay eggs, or pupate during the coldest or warmest months. As temperatures have increased, some species of butterfly have moved farther north to continue to live in their traditional temperature range. Other butterflies have moved higher in elevation to reach cooler climates, as shown in a recent study that documented the change in range of a North American butterfly species known as Edith's Checkerspot (*Euphydryas editha*). In some locations for some species, however, there is no higher elevation to climb. Butterflies are not the only species to shift their range to inhabit cooler climates. A 2003 study showed that some species of plants and animals have shifted toward the Poles at an average speed of four miles (six kilometers) per decade since 1950.

Temperature-sensitive mountain species of mammals from marmot to pika are also seeing the impact of a warming planet. In the case of the pika, a species of alpine rodents whose closest relatives are rabbits and hares, 7 out of 25 populations known from the 1930s had gone extinct when their ranges were resurveyed in 2003. Experiments have shown this animal to be so sensitive to warming that after a mere half-hour exposure to temperatures of 88°F (31°C), an adult pika could die from heat.

The Monteverde golden toad was a species once found in the cloud forests of Costa Rica but perished due to a changing environment.

One of the first confirmed species to disappear due to changing environments is known as the Monteverde golden toad. First described and discovered by scientists in 1966, this toad was found in the Monteverde Cloud Forest of Costa Rica. The well-studied species disappeared as a warming climate caused the mists of the cloud forest to move above the tree line. Without the moisture of the mists, the frog could not survive, and the last of its kind, a lone male, was seen in 1989.

More recent studies theorize that this species was actually a victim of El Niño, which alters local weather for months to years (Curry 2010). If this species perished due to El Niño, which is a shorter term change in the environment, think about how other organisms could be affected by long-term climate change.

During the first global survey of amphibians in 2004, more than 6,000 species were described—a third of them were threatened with extinction. Many amphibians are suffering from the effects of habitat degradation and pollution, and global climate change exacerbates these problems. In some species, such as the Monteverde golden toad, a slight change in the environment is enough to dry up their habitats for mating, egg laying, and tadpole ponds or generally alter their habitat beyond conditions that they can survive.

Some species may be able to survive and thrive in a changing climate, while others will not be able to adapt as quickly. Humans have the advantage of being capable of moving away from unfavorable conditions and insulating ourselves from many of them. Many other species on Earth will be left to face the new conditions. Models on how changing populations and food webs will impact entire ecosystems in the future are just being developed. For many species, it will be a matter of wait-and-see to distinguish which species will survive on our changing planet.

Teaching Tip

Students don't need to wait to graduate from college or even high school to help scientists track trends in animal sightings across the nation. Several citizen or community science projects enable even the novice to collect data. The Great Backyard Bird Count is a great way to get students involved. Sponsored by the Audubon Society and the Cornell Lab of Ornithology in the United States and by Canadian Partner Bird Studies in Canada, the count is held in February of each year, with people all over North America counting the birds they see in their backyard, schoolyard, or local park. At the end of the count, each participant enters the data online to help create one of the largest birdcount databases in world. The compiled data helps scientists gain a better grasp of how global climate change is impacting birds and their migration patterns. Often times, local Audubon Society Chapters, Wild Birds Unlimited stores, or ornithology clubs will come to classrooms to help students learn the basics of birding before the big count. For more information, check out: http://www.birdsource.org/gbbc/ or http://conservation.audubon.org/programs/great-backyard-bird-count.

The Human Impact

Humans will probably see a variety of impacts from global climate change—from changing weather and food supplies to changing land use and changes in water supply. Scientists and government officials both predict that those people who are at a socio-economic disadvantage will experience more negative impacts than those who are insulated by wealth. For example, fresh, clean drinking water is more readily available to people who can afford clean or bottled water. As dry areas become drier as a result of climate change, access to water will be more limited in those places.

In contrast, diseases such as malaria and West Nile virus that are spread by infected mosquitoes do not discriminate based on wealth. Some models predict that more mosquitoes will thrive in the warmer, wetter climates of our future. The possible increase in spreading of mosquito-transmitted illnesses is one example of a public health risk related to global climate change impacts.

Models Are Science in Action

One of the most important things to know about models is that they represent science in action. They embody the best information available at the time they are created. As new information comes to light over time and new data and technology become available, models can, and probably will, change. This does not mean that results from earlier versions of the model should be considered wrong; it just means they were based on the best science possible at the time.

What is certain is that things will continue to change. Observational data confirm that climate conditions are changing, and projections from models indicate that conditions will continue to change. Even though current models will change or different models will produce slightly different results, it does not mean we should dismiss all projections from models. An anecdote that illustrates this relates to our understanding of the solar system: When Copernicus first proposed that Earth and the other planets revolved around the sun—as opposed to the prevailing theory of the time that Earth was the center of the galaxy— he listed only six planets in the solar system. Most students understand that, although we have discovered more planets since that time, our new knowledge does not mean that Copernicus was wrong. This story can help students understand how science advances and how models can build our understanding of global climate change.

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6 Solutions for a Changing Climate

by Jose Marcos-Iga and Tania T. Hinojosa

"We cannot make the mistake of thinking that just because scientists tend to focus on the 10 percent they don't know, the 90 percent they do know isn't already a call to action."
Friedman (2008)

Climate change is the preeminent socio-ecological issue of our time. Every person will need to understand climate change in order to participate in decision-making that will affect our future and our way of life. Climate models predict that continued warming will have an impact on energy, water, transportation, agriculture, health, and ecosystems in the following decades (IPCC 2007). The solutions we choose to address these problems will impact our economy, our city planning, and our everyday way of life and consumer practices.

Understanding the science behind climate change will be critical to the citizens who will be making choices for their own lives or empower their political leaders to make choices on behalf of their communities. Encouraging a new generation of students to study climate change, especially solutions, is important so that their understanding of the topic continues to grow.

As we have seen in the preceding chapters, there is consensus in the scientific community that climate change is real and that humans play a key role in accelerating the process. Likewise, we are capable of slowing it down. Then, why have we done so little about it?

A 2010 study by the Yale Project on Climate Change Communication titled "Global Warming's Six Americas" shows that 39 percent of American adults are either "alarmed or concerned" about climate change while 29 percent remain doubtful or dismissive (Leiserowitz

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.2 3.3.3 3.4.1-2 3.5.1-3	The Geography of Where We Live California's Economy—Natural Choices
Grade 4	4.1.3-5 4.4.6 4.5.3	Reflections of Where We Live
Grade 5	5.7.3	
Grade 6	6.6.a 6.6.b	Energy: It's Not All the Same to You! Energy and Material Resources: Renewable or Not?
Grade 7		
Grade 8	8.3.6 8.12.5	 Industrialization, Urbanization, & Conservation

et al. 2010). Why is the alarmed and concerned 39 percent of the population not acting on their concerns? How can we bridge the gap between concern and action? Is education the answer?

A similar report titled Climate Change in the American Mind found that, even during the economic downturn, 90 percent of Americans think the United States should act to reduce climate change, even when there is a financial cost involved (Leiserowitz et al. 2010). Furthermore, more than 73 percent believe that climate change will harm Americans within the next 50 years, and 47 percent believe the harm is already being done or will be, within the next 10 years. Still, only a few alarmed Americans (8 percent) have actually contacted their elected officials about the issue within the last year.

Why are values not aligning with action? According to a report from the American Psychological Association (APA 2010), there are many emotional barriers that stand in the way of actions that would help solve the problem. Climate change is about large-scale systems over long periods, with uncertain outcomes. Research shows that while scientists generally are more concerned with long-term global

CHAPTER OVERVIEW

Taking action against climate change may seem daunting to some citizens, especially our students. Given a better understanding of climate change, students may develop a sense of empowerment and belief that even the smallest of actions can aggregate to have large-scale change.

This chapter discusses four types of solutions necessary to take action against climate change. Mitigation is one solution that focuses on reducing the causes of climate change. For example, regulating carbon dioxide emissions from vehicles is one mitigation strategy. Mitigation strategies are made possible through a second type of solution—innovation. With new innovative technologies, we can change the way we consume fossils fuels and the way we alter our landscape. New innovations can be factored into mitigation plans. Action on the part of people is a third solution that influences both mitigation and innovation. When people—as voters and consumers—place pressure on business and political leaders, those leaders and business owners will be more likely to listen to the needs of people in order to stay in office or stay in business. A last solution to climate change is to prepare for the changes already underway. Our communities are already faced with changes, and we will need adaptation strategies in order to cope with them.

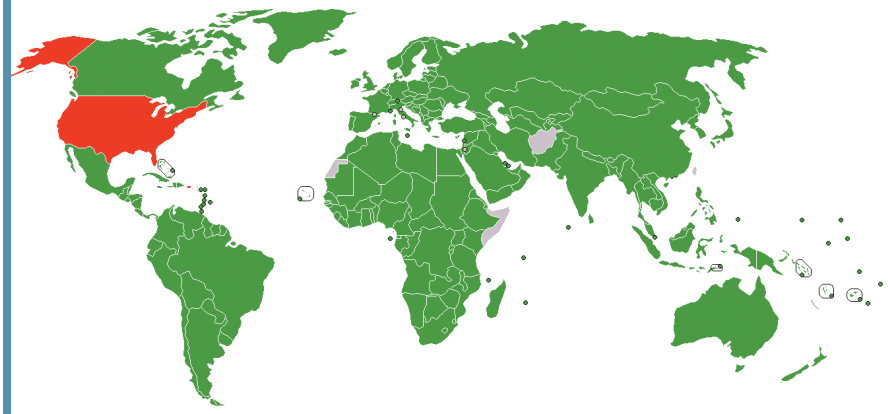
problems, the general public tends to be more concerned with immediate, local issues. Sterman and Booth Sweeney (2002) found that large time scales and the large scope of the climate crisis "dwarfs normal human concern" (p. 2). Time is a relative factor, and youth, in particular, may view a "long" time as a month or year, as opposed to a decade or longer.

Public perception is also a key component. People may have other worthy goals and aspirations or be worried about threats and problems that seem more pressing in time and space, such as pandemics, war, or an economic crisis, which draw from their time, effort, and resources. They may feel overwhelmed by the problem of climate change or believe that solutions outside of human control will address it. As a result, people may fall into a place of passivity, inaction, and disempowerment. So while people may believe they should act, they may also believe their actions have no real influence. In many cases, the very same individual may be engaged in actions that show immediate positive impact on local environmental issues because results are more immediate and tangible.

A special burden is placed on educators with respect to climate change education, especially educators of science and social studies. Teachers must help students make the connection between climate change at the global level with impacts at the local level and help students see that there are real actions they can take in their community to help—actions that when aggregated on the large-scale will have profound impacts.

In this chapter we talk about the many solutions that are being discussed, developed, and implemented by many governments, organizations, enterprises, and individuals around the globe. They are concentrated in four key areas:

KYOTO PROTOCOL PARTICIPANTS JUNE 2009



Countries that ratified the Kyoto Protocol as of June 2009 are shown in green. Grey indicates countries that are undecided, and red indicates countries that have signed, but with no intention to ratify.

- Mitigation: What laws and regulations are being considered to slow down the pace of climate change?
- Innovation: What exciting initiatives or discoveries are underway for new technologies or new sources of energy?
- Adaptation: As the effects of climate change reach our doors, how will people adapt to a new reality on a changing planet?
- Action: What can your school, your students, and your community do to make a difference?

Mitigation

For climate, mitigation refers to actions that decrease greenhouse gas emissions or increase their capture. Examples of climate mitigation include establishing new standards to make vehicles and appliances more efficient, switching from fossil fuels to renewable energy sources for generating electricity, and setting a limit on the total amount of emissions industries can put into the air. Planting new trees and protecting existing forests from being cut down are also examples of mitigation.

The Earth Summit and Kyoto Protocol. More than 15 years ago, the UN Framework Convention on Climate Change (UNFCCC), an international treaty ratified by 193 countries, entered into effect. The treaty was the outcome of the UN Earth Summit, held in Rio de Janeiro in June of 1992 with the goal of

Definition of Mitigation

The IPCC defines ***mitigation*** as "technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce GHG [greenhouse gas] emissions and enhance sinks."
IPCC AR4, 2007, p. 818

considering climate change mitigation and adaptation strategies and policies. More recently, several nations agreed on an addition to the treaty, which we know today as the Kyoto Protocol. The Kyoto Protocol, which is more widely known today than the UNFCCC, included updated and significantly more powerful measures for mitigation of climate change.

While the Rio de Janeiro Convention encouraged industrialized countries to reduce their greenhouse gas (GHG) emissions, the Kyoto Protocol actually committed countries to targets to achieve reduction goals. The UNFCCC target for 37 industrialized countries and the European Union was set to an average reduction of 5.2 percent from 1990 levels by the year 2012. The protocol was adopted in Kyoto, Japan, in December 1997. To date, 184 countries have ratified the the Kyoto Protocol, but the United States is not one of them.

Nonetheless, within the United States, an impressive move on the part of individual states and cities has shown increased support for the Kyoto Protocol measures and goals. The U.S. Conference of Mayors' Climate Protection Agreement has the support of 1,044 mayors, each pledging to reduce his or her city's carbon emissions below the 1990 levels (U.S. Conference of Mayors 2009). Regional initiatives in the United States include the Regional Greenhouse Gas Initiative (RGGI), comprised by states in the Northeast and Mid-Atlantic regions of the country (RGGI 2010). A similar effort is taking place on the West Coast, through the Western Climate Initiative (WCI). California, one of the key partner states of the WCI, has taken the lead in mitigation efforts (WCI 2010). In 2006, California's former governor Arnold Schwarzenegger signed the Global Warming Solutions Act (California Energy Commission 2008). In the following pages we present a case study showcasing California's strict emissions policies and practices.

Copenhagen Climate Change Conference, 2009. The 15th meeting of representatives of the UNFCCC took place in Denmark in 2009. The Copenhagen Accord, the international agreement that was developed during that meeting, included the long-term goal of limiting the maximum global average temperature increase to no more than 2°C (3.6°F) above pre-industrial levels. There was, however, no agreement on how to accomplish this goal in practical terms. Participants did make progress on establishing the infrastructure needed for effective cooperation and in narrowing options that could be followed, but the meeting was also marked by controversy, especially over the divide between developed and developing countries.

Another issue that received much attention in Copenhagen was the emission trading approach known as **cap-and-trade.** The cap-and-trade approach works in two levels: The cap limits the amount of greenhouse gases a polluter can emit. Companies will need to acquire emission permits, which allow them to release a certain quantity of GHGs into the atmosphere. The trade part allows for companies effective in reducing their emissions to sell their permits to companies that need additions to their own permits. This system controls the overall emissions from companies, while allowing effective GHG reducers to profit from the trade—an incentive for GHG polluters to reduce emissions and invest in clean energy sources.

One of the main issues with the cap-and-trade system is determining the "starting" level of emission permits given to companies. There is some concern about the possibility that some governments might "grandfather" or give away initial permits to polluters based on their current level of emissions. Not only could this potentially "reward" polluters, but also it could also increase the inequity between the rich countries and big companies and the smaller players. Some of the alternatives being proposed include governments auctioning the initial permits and recycling the revenue back into the economy to invest in green (or more environmentally friendly) technology to offset energy price increases and to facilitate a smooth transition to a low-carbon economy (Leonard 2010).

Tips for Teaching

The United States has signed but not ratified the Kyoto Protocol. The signature alone does not bind a country to the protocol mandates unless it ratifies the protocol. Students might find this difficult to understand. This is a great opportunity for a class discussion and reflection. Ask your students: Why do you think our country leaders at the time decided not to ratify the protocol? What are the consequences of this? What would have happened if we had actually ratified the protocol?

Case Study

What's So Cool About California?

California is at the helm of climate-change mitigation initiatives. The government of the state of California decided the debate on climate change was over by passing the Global Warming Solutions Act of 2006, an environmental law, signed by former Governor Arnold Schwarzenegger on September 27 of that year. The bill established a timetable and the measures necessary to bring California closer to the goals of the Kyoto Protocol. This bill was the first approved legislation by any U.S. state to cap emissions across all economic sectors. California, where one out of eight Americans live, now requires major industrial producers to reduce emissions 25 percent by 2020. In other words, California has to cut its annual release of carbon dioxide by 174 million metric tons. The reductions are so significant that it would take a forest twice the size of New Jersey to process all those emissions (California Energy Commission 2008).

In order to achieve these goals, California has set a series of key strategies in six areas. The strategies are taken from the California's Climate Plan Fact Sheet (California Energy Commission, 2008). Visit http://www.climatechange.ca.gov/ to see complete versions of each strategy and learn more about California's climate plan.

Santa Rosa CityBus uses diesel-electric hybrid buses.

Solar panels transform light energy into forms of energy we can use.

Cap-and-Trade Program. By setting a limit on the quantity of greenhouse gases emitted, a well-designed cap-and-trade program will complement other measures in California. The program provides a firm cap on 85 percent of the state's greenhouse-gas emissions.

Transportation. California will reduce 30 percent of its vehicle greenhouse-gas emissions by 2016. By 2020, California will decrease by 10 percent carbon-intensive vehicle fuels through its low-carbon fuel standard. Other transportation measures include using more efficient delivery trucks, heavy-duty trucks, and goods movement.

Electricity and Energy. California continues to improve appliance and building standards. By 2020, a total of 33 percent of the energy used in the state will come from renewable sources. Other efforts include the following programs: Million Solar Roofs; Solar Hot Water Heating; Green Buildings; and water efficiency.

High Global Warming Potential Gases. In order to minimize gases that potentially influence global warming, the state is making an effort to capture high global-warming-potential gases already in use. California is also reducing future impact by encouraging the use of leak-resistant equipment, putting restrictions upon use of products that release these gases, and imposing additional fees.

A former industrial site is replanted with trees.

Forestry. California is making an effort to preserve forest sequestration by minimizing the cutting down of forested areas so the protected trees will continue to take up, or sequester, carbon dioxide from the atmosphere. Additionally, California is reducing atmospheric carbon dioxide by encouraging forestry projects in which new trees are planted.

Agriculture. The agriculture industry in California contributes to production of carbon-dioxide emissions, as well as the release of other GHGs. In order to reduce the impact of agriculture on climate change, California is promoting the use of more efficient agricultural equipment and by minimizing fuel and water use through transportation and energy measures.

Changing Energy Portfolio. In early 2011, the state of California voted to increase its Renewable Portfolio Standard (RPS) to 33 percent by 2020. This legislation means that renewable energies must comprise 33 percent of utility companies' retail sales by that time.

Explore More

Cool California is a great resource created as part of the efforts under the Global Warming Solutions Act. This website, created through a partnership between government, universities, and nongovernmental organizations, offers a toolkit for schools, as well as success stories that can inspire your students to act in their school and community (California Air Resources Board 2010). Examples include:

- The city of San Diego reduced its GHG emissions by 3,814,000 tons between 1999 and 2003. Between 2003 and 2010, the city had a target to reduce an additional 5,488,000 tons to accomplish its goal (California Air Resources Board). Explore more at http://www.coolcalifornia.org/case-study/city-of-san-diego.
- Solar capacity in the city of Santa Monica has doubled since the launch of its solar program (Solar Santa Monica). To date, there are 139 grid-connected solar projects in the city, representing 926 kilowatts of solar capacity. Explore more at www.coolcalifornia.org/case-study/sustainable-santa-monica.
- In 2001, Marin County became the first local government to calculate its ecological footprint. Marin County has set a target to reduce GHG emissions 15—20 percent below 1990 levels by the year 2020 for internal government and 15 percent countywide. Explore more at www.coolcalifornia.org/case-study/reducing-residents-ecological-footprint.
- Reforest California is a million-tree challenge to help raise funds to replant trees in Southern California State Parks that have been impacted by wildfires (The Coca Cola Company 2009). Explore more at www.reforestcalifornia.com.

Pictures of Practice

Our Different Carbon Footprints

Students often have trouble identifying indirect actions that result in a large carbon footprint. They identify cars as major producers of CO_2, but only think of it in terms of human transportation, as opposed to the transportation of goods. Students also have a hard time conceptualizing the manufacturing of goods such as clothing, in which the raw materials are transported to one country where the fabric is created, another country where the garments are assembled, and still another country where they are sold. When looking at these hidden contributors to climate change, it may be best to give examples that students are familiar with. Groceries such as apples, tomatoes, and milk are good examples of items students come into contact with at local stores. By using real-life examples, students can understand that their carbon footprint branches out not only to what they do, but also to what they chose to buy, and how and where it is produced. It is also important to have your students look at the big picture, and this often means having them compare the carbon footprint of a typical person in the United States to someone in a developing country. Showing examples of different ways that the same task is done can help students understand how some countries contribute more to climate change than others.

Students: Grade 6

Location: South Gate, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss what a carbon footprint is.

Classroom Context

Ms. Walker taught a two-week unit on climate change and concluded the unit with lessons on carbon footprints. During her lessons, students began to compare an American carbon footprint with the footprint of people in other countries. This video represents students' ideas after several lessons about climate change.

Video Analysis

This video begins with Ms. Walker asking her class what *carbon footprint* means. A carbon footprint is determined by one's daily practices and the amount of CO_2 emitted into the air because of those practices. Carbon footprints in industrialized countries tend to be much greater than those in developing countries because of the use of fossil fuels and consumer practices. To start the discussion, Ms. Walker uses a common grocery item, milk, to demonstrate that many items students consume are indirectly linked to carbon dioxide through production and transportation. This point was driven home in the class when students began to discuss how their grandparents (many located in Mexico and Central and South American countries) had a smaller carbon footprint because they did things such as walk to the market, eat locally-grown produce, and wash their clothes by hand. In the end, Alan's post interview shows he has a good handle on the definition of carbon footprint.

Reflect

What key concepts would you teach on the carbon footprint? Why?

Ms. Walker was able to help her students understand that consumers contribute to carbon footprints. She was also able to drive the idea home that different countries often have different carbon footprints because so many of her students had firsthand experience with families (their own and others) from another country. What concepts do you think are most important to teach about the carbon footprint? How would you address the issue of unequal carbon footprints between industrialized and developing countries?

Pictures of Practice

Climate Action

Once students know what climate change is and what causes it, the next step is helping them to understand practical ways they can help reduce their own contributions to it. This can be difficult, because often students are told about car emissions and industrial emissions, both of which seem out of their control. They also may believe that reducing emissions to below previous levels would mean going back to "simpler times." Ideas such as using more candles or washing clothes by hand may sound good in theory but are not practical solutions for everyday life. It is important that students understand that other actions, such as reducing consumption of disposable items, increasing recycling, and unplugging electronics when they are not being used can go a long way in contributing to an overall decrease in carbon emissions and climate change.

Students: Grade 6

Location: South Gate, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss "the old-fashioned way" as a solution to climate change.

Classroom Context

Previously, Ms. Walker had talked with students about their carbon footprints and identified that students in America have a larger carbon footprint than their peers in developing countries. The discussion of carbon footprints led to a discussion of actions to reduce carbon emissions.

Video Analysis

In this video, you will see students brainstorm what they can do to help reduce their carbon footprints and slow down climate change. Interestingly, students propose that people go back to "the old-fashioned way of doing things." For example, students propose washing clothes by hand and milking cows by hand. While these solutions correctly identify industry and electrical appliances as contributors to climate, in reality these solutions are not practical ways to solve our climate problems. Ms. Walker asks her students if they are willing to do things the old-fashioned way or willing to pay more for others to do these tasks. Ms. Walker surveys the class on who would be willing to do that, and many students agree. She then goes on to ask what milking cows by hand would do to the cost of milk, and students concede that it would go up. Students then agree that they would not want to spend more money for milk, and Ms. Walker ends with the question: "How are we going to solve our carbon dioxide problem?"

Reflect

How would you respond to ideas about the old-fashioned way?

Notice that students' previous discussion about carbon footprints in developing countries influenced their ideas about how to solve climate change. They suggested going back to old-fashioned methods such as hand-washing clothes and milking cows by hand because these tasks are done by family members in developing countries. How would you respond to these students' ideas? What climate actions would you focus on in your instruction?

Alternative Energy

When learning about mitigation initiatives, community leaders, the general public, and especially educators, might ask, "what can we do?" The answer? "Turn to renewable resources!" While nonrenewable resources, such as coal and petroleum, will eventually be used up, renewable resources can be regenerated. Virtually as long as there is Earth as we know it, there will be wind, water, and sun. Some might suggest that one solution is to use renewable, or clean, energies; but most would agree that we need to learn to use energy wisely. However, just exactly what are these clean options? This section will review the benefits and possible negative impacts of renewable alternatives to the burning of fossil fuels for energy.

Hydroelectricity. **Hydroelectricity** is also known as hydropower. This energy is generated by water movement. It is ultimately derived from sunlight, which drives the water cycle, and gravity, which causes water to flow downward. A hydropower plant uses the energy of motion in flowing water to rotate a turbine, which activates a generator to produce electricity. In creating the dams that produce hydroelectric power, habitats can be destroyed, and animals can be driven to the brink of extinction as flows are changed dramatically. (The Environmental Education Exchange 2004).

Wind Energy. The harvesting of wind energy occurs as the motion of the wind is used to spin wind turbines, which transforms mechanical energy into electric energy. This process produces no solid waste, hazardous waste, water pollution, air pollution, or greenhouse gases. However, the spinning blades of the turbines can kill or injure migrating birds passing by, and there are visual and noise considerations.

Biomass and Bioenergy. Bioenergy is energy made available from **biomass.** Biomass is material from biological sources and includes plant matter such as trees, grasses, and agricultural crops, as well as solid waste, animal waste, and food-processing wastes. Biogas, the gas from the decomposition of organic matter, is a form of biomass. Methane is a common form of biogas collected from landfills. Other than biogas from landfills, the process of creating biomass and bioenergy tends to be water intensive, and there are concerns about food crops being diverted to biogas production, leaving many people hungry (The Environmental Education Exchange 2004).

Geothermal. **Geothermal power** is derived from Earth's internal geological processes, such as volcanic activity. Geothermal power can be a cost effective and **sustainable** source of electricity but in the past has been limited to areas near tectonic plate boundaries. Additionally, there is some concern that the drilling for geothermal power can impact an area in strange and possibly dangerous ways as it changes local geological and tectonic forces.

Passive and Active Solar Energy. Solar energy is the energy that comes from the sun. Use of solar energy might be passive or active. A passive use of this energy is orienting a building to take advantage of sunlight. For example, sunrooms in a home use passive solar energy to warm them. Active solar energy involves the use of electrical and/or mechanical equipment. Two types of active solar energy are **photovoltaics** and solar thermal collectors.

Photovoltaic energy (PV) is created when sunlight is converted directly into electrical energy. PV technology can be used to provide energy on almost any scale, from calculators to a single private home to large-scale commercial power plants. Active solar energy, such as photovoltaic, tends to be very expensive, and it still is not as efficient in capturing the sun's energy as would be ideal (The Environmental Education Exchange

2004). Solar thermal is another active-solar option, in which sunlight is collected and concentrated to become heat, which may be used to warm a liquid or to warm a space.

Ocean Energy. Ocean energy is a clean, renewable source of energy with no by-products and a relatively consistent source. Think about how reliable energy would be if it was generated at every high and low tide or using the power of our ocean currents? However, environmentalists are concerned about the impact on marine animals and the environment. New construction, whether offshore or coastal, could change animals' habitats and migration patterns, similar to the impact of dams on salmon. Furthermore, the energy must be transferred to the preexisting electrical grid. The farther the energy is transferred, the more energy is lost by the time it reaches its destination.

Nuclear. Energy resulting from fission, or the splitting of uranium atoms, is known as nuclear energy. Even though uranium is a nonrenewable source of energy—there is a finite amount of it in our planet—nuclear energy is considered by many to be a clean source of energy, because virtually no greenhouse gases are being released. Nonetheless, many argue against the use of this type of energy because of safety concerns related to radioactive waste that is harmful to humans.

Teaching Tip

What do students know about where their energy comes from? Do they know the ultimate source of energy for the electricity they receive in their homes? How far can they trace back their energy?

- Students may struggle with understanding energy transformations.
- Students often confuse electricity with energy. They do not necessarily understand that electricity is a secondary form of energy, obtained through a primary source.
- Power plants (especially what goes on in a power plant and how the "power" gets to homes) can be a mystery to students.
- Students tend to perceive electricity as a clean source of energy, because they cannot see the pollution being released at the power plant.

Take **biofuels** as an example. How might energy transformations get confusing and complicated for students when discussing biofuels? Why are biofuels being considered? (In the simplest form, plants are net zero for carbon emissions.) However, it takes energy to make energy, and biofuel production actually uses more energy in the process than we get out of the fuels.

Geoengineering: Where Mitigation Meets Innovation. Also known as climate engineering, this concept groups a set of practices that involve large-scale engineering of our environment to mitigate the effects of changes in atmospheric chemistry (National Academy of Sciences 1992). One controversial example of this is iron fertilization of the oceans—adding large amounts of iron to the ocean waters to feed the algae that absorbs carbon dioxide. This is similar in intention to reforestation, as we are increasing the capacity of our oceans to sequester greenhouse gases. The controversial nature of this practice is related to the unknown possible impact a sudden increase in algae population might have in the ocean's ecosystem.

Case Study

Solar Energy

Adapted from *Powering Our Future: Renewable Energy Education* (The Environmental Education Exchange 2004)

The sun is the ultimate source of energy on Earth. The sun drives water cycling and wind and weather patterns and is the source of energy for all life on Earth. This means that solar energy is the ultimate source of many other energy sources on Earth, including fossil fuels, biomass, and wind. Of course, the term *solar energy* is commonly used to refer to the forms of energy that we obtain more directly from the sun. Sunlight, also called solar radiation, is the most inexhaustible, renewable source of energy known to humankind. The amount of energy that the sun radiates onto Earth every hour is greater than the amount of energy used worldwide in a full year.

In general, the ways we use the sun's energy can be described as passive or active. Passive solar energy involves using the sun's energy with no or minimal mechanical or electrical devices. Passive solar energy can involve using the sun's energy as a light or a heat source. Lighting buildings with natural light is called daylighting. Passive applications of solar thermal energy, or the heat energy of the sun, include heating water and buildings. Using passive solar techniques for heating is very efficient. Heat energy is considered low-quality energy. Electricity, for instance, is a high-quality energy because it is very concentrated. When electricity is converted to another form, heat, a low-quality energy, is given off. Using electric heat, for instance, is inefficient. You are using a high-quality energy source for a low-quality need. A lot of energy is "wasted." Passive thermal systems prevent this type of waste. This is because the energy is used in the same form (heat) rather than converted from one form to another.

Active solar energy is any type of solar application that uses electrical and/or mechanical equipment. Solar thermal power plants are an example of active solar thermal application. At such plants, sometimes called "power towers," the sun's rays are concentrated as a heat source to boil water or another fluid, producing steam. The steam is used to rotate a turbine, activating a generator that produces electricity. This is very different from photovoltaic energy.

British Motor Car Distributors in San Francisco, California, installed solar panels on their carports to supply the dealership with enough power to meet its daily energy needs.

Photovoltaic, or PV, energy is a form of active solar power that is created when light energy from the sun is converted on an atomic level directly into electrical energy. Photovoltaic technology actually produces electricity with no moving parts and without burning fuel. PV technology is based on an interesting fact of physics and chemistry that light energy can stimulate an electrical current in certain materials or semiconductors.

The basic building block of all photovoltaic systems is the photovoltaic cell. The PV cell is where the energy conversion process takes place. Although other materials can be used, today almost all photovoltaic cells are made of a very thin wafer of crystalline silicon. Silicon is the second most-abundant element in Earth's crust (the first being oxygen). The photovoltaic effect occurs when sunlight strikes silicon (or certain other semiconductors) and the light energy is absorbed, energizing electrons so that they become free from their atoms and move through the material. A PV cell is designed to enhance this natural process. By connecting the cell to a circuit along which the electrons can flow, we can harness the electricity and put it to use.

More than 3,300 solar panels have been erected on a vacant five acres at NASA's Kennedy Space Center in Florida to create the Solar Energy Center.

Sunlight is comprised of a range of wavelengths. It is light energy, per se, that causes the photovoltaic effect. The heat energy in sunlight is central to solar thermal applications, like passive solar buildings and water heaters, but plays no role whatsoever in photovoltaics.

The performance of a PV cell is measured in terms of its efficiency at converting light energy into electricity. Some types of PV cells available today reach efficiencies of about 15 percent. *Efficiency* refers to the amount of energy that is actually obtained from a process, as much energy is lost as heat when it is converted into electricity or other forms. As per the laws of physics, no conversion of energy can be 100 percent efficient. For comparison, use of fossil fuels to create electricity is about 30 percent efficient; that is, 70 percent of the energy is lost during conversion and transport.

Photovoltaic power has proven extremely reliable. A photovoltaic array has no mechanical (or moving) parts, and PV equipment can operate reliably for long periods with virtually no maintenance. No fuel or input is required other than sunlight. Because sunlight is free, there are no fuel costs (and no unpredictable variations in fuel costs over time). The cost of a PV system is almost entirely paid up front for equipment and installation, and operating costs are quite minimal. Developing PV plants, however, can be very expensive.

Producing PV cells does result in some pollution. However, in contrast to electricity generated by conventional energy sources, photovoltaic electricity does not involve the release of greenhouse gases and other air pollutants, production of toxic or radioactive waste, large PV projects can cover thousands of acres, which disrupts the natural ecosystem. The downside of using photovoltaic power is the high cost of the technology and the habitat loss when solar plants are built in pristine habitats. Of course, solar units cannot generate power at night and are less efficient during cloudy weather. Also the storage of energy from PV plants can be a challenge. Although solar panels are expensive, the price of PVs is decreasing and will continue to do so as the technology improves and more homes and businesses purchase it.

Student Thinking

Renewable Resources

Often, students are introduced to renewable energy resources as a "no harm" energy alternative to traditional fossil fuels such as oil, coal, and natural gas. While students are interested in learning about renewable energy, they often have misconceptions that may hinder their understanding of these resources. They may also be confused about how to determine whether an energy source is renewable or not.

	Common Student Ideas	Scientific Concept
Impact on Environment	Renewable energy resources have no negative impacts on the environment.	Harnessing renewable resources can endanger wildlife and disrupt ecosystems.
Biofuels	It is only the heat produced by burning biomass that can be used for energy (such as burning firewood).	While biomass can be burned to create heat for cooking and heating, biogas can also be used as organic matter decomposes, creating natural gases such as methane. Biogas from landfills is a viable option, but scientists are worried that biofuels from crops is too labor-intensive and may divert food and water from food-crop production.
Efficiency	Renewable energy resources are 100 percent efficient.	No energy resources are 100 percent efficient. In fact, some renewable energy resources, such as solar power from PV cells (see **Case Study: Solar Energy,** page 98), are less efficient than fossil fuels.
Nuclear Energy	Nuclear energy is renewable because it is considered a "clean" form of energy.	Nuclear energy emits virtually no greenhouse gases, so it is often lumped together with renewable resources. However, there is a finite amount of uranium on the planet, and therefore, it is not renewable.

Ask Your Students

1. What kind of impact do renewable energy resources have on the environment?
2. How is biomass such as wood, agricultural crops, and so on, used to create energy? Are there any drawbacks to using biofuels?
3. How efficient are renewable energy resources?
4. Is nuclear energy renewable?

Adaptation

According to the latest assessment by the Intergovernmental Panel on Climate Change, very specific information is currently available across a wide range of sectors concerning the nature of future impacts of climate change. The following is an overview of some of the most important concerns.

Effects of Climate Change.

Scientific evidence shows that climate change will likely have significant costs, and the problem will continue to grow over time (IPCC 2007). Scientists have observed and recorded many changes on our planet that are caused by global climate change. All of these changes impact plants and animals in the natural world, but because humans are also part of the natural systems, we are vulnerable to the negative effects of climate change as well. Many of the effects predicted by scientists in the recent past as a result of global climate change are now occurring: loss of sea ice, accelerated sea-level rise, and longer, more intense heat waves.

There is high confidence among the scientific community that global temperatures will continue to rise for decades to come, largely due to greenhouse gases produced by human activities. The Intergovernmental Panel on Climate Change (IPCC) predicts a temperature rise of 2.5 to 11.5 degrees Fahrenheit (1.4 to 6.4 degrees Celsius) over the next century.

According to the IPCC, climate change effects will vary in individual regions over time, and the ability of different groups of society and environmental systems to mitigate and adapt to change will depend upon many socio-economic, political, and natural factors.

Island nations may be affected most by climate change. These nations may need to reserve money to adapt as their coastlines change.

Adapting to Climate Change Effects. There are many actions we can take to adapt to climate change, ranging from technological strategies (e.g., sea defenses) to behavioral changes (e.g., altered food and recreational choices) to the way we manage our food systems (e.g., altered farm practices) and policies we pass at the local to national levels (e.g., planning regulations).

The following are adaptation strategies provided by the Environmental Protection Agency (EPA 2010). More information about these strategies can be found directly on the EPA website: www.epa.gov/climatechange/effects/adaptation.html.

Human Health

- Prevent an increase of diseases in a world of climate change by providing sufficient public-health resources.
- Provide alerts to the public regarding dangerous weather or heat advisories and information about actions to take in excessive weather and heat conditions.
- Develop systems for storing grain and plans for emergency feeding stations.

As sea level rises, we will need to plan for repairs and replacement of existing coastal structures.

Coastal Areas and Sea Level Rise

- Develop maps and plans for areas requiring shore protection to determine areas with the greatest need of help. Determine the most sustainable action for shore protection to reduce negative environmental consequences.
- Map wetland areas in danger of negative consequences from sea-level rise, and develop plans for managing these areas.
- Protect water supplies that may be contaminated by saltwater.

Agriculture and Forestry

- Adapt to changing growing conditions by 1) altering planting dates, 2) altering crop selection for new climate conditions, and 3) breeding new species tolerant to changes in conditions.

Water Resources

- Promote conservation and change water demand by human communities
- Improve water-use efficiency.
- Develop plans for alternative water sources (such as treated wastewater or desalinated seawater).

Energy

- Promote energy conservation by human communities.
- Increase energy efficiency.
- Develop energy plans that include diverse alternatives and backup supplies in the event of failures of power plants.

Ecosystems and Wildlife

- Develop plans to manage and protect wildlife populations by 1) promoting wildlife corridors that allow wildlife to migrate with climate, and 2) developing plans for conservation.
- Develop strategies to promote resilience in ecosystems.

The American pika may be a victim of climate change in the future. They live is high alpine areas of the western United States and are sensitive to temperature changes.

Careful planning for water resources will be important for a future with changing precipitation patterns. We need to ensure water for our homes and agriculture without taking too much from our natural systems.

Teaching Tip

It is important to make the issue of climate change personal. Seeing the direct relevance and urgency of the issue will help your students truly understand the need for each of us to modify our lifestyles. This will be especially important as the effects of climate change become more evident. The following scenarios are interesting problems to make climate change more personal for your students:

- What if sea level rises 2 feet (61 cm)? How will California be affected? How will I be affected?
- What if precipitation decreases by 5 inches (12.7 cm) each year? How will California be affected? How will I be affected?
- What if ocean organisms began to move to different areas as the temperature and chemistry of the ocean changes? How will the California economy be affected? How will I be affected?
- What if crops that are dependent on specific climates, such as vegetables in California, have trouble surviving, are not as good quality, or both? How will the California economy be affected? How will I be affected?

Action

Given that many adult Americans express a sense of feeling powerless against climate change, imagine how young students may feel. But there is much you and they can do as consumers, as citizens of this country, and ultimately as inhabitants of planet Earth.

What Can You and Your Family Do?

Use Your Consumer Power. Make choices as consumers to support sustainable companies and sustainable products. Reward those companies with consumer support.

Follow the Three R's. The order of the three R's (Reduce, Reuse, and Recycle) is not arbitrary. Some people tend to think of recycling first, and of reducing and reusing as less important, but this is incorrect. If we start by reducing the amount of new things we purchase or buying only things we need, we can make less trash. Reducing is actually the most efficient way to conserve resources, followed by reusing. We can reuse things we have and avoid buying single-use items (such as plastics utensils and paper plates). Recycling is also important, but is not as efficient as reducing and reusing. All three, however, are important practices for protecting our natural resources.

Reduce Your Carbon Footprint. A carbon footprint describes the amount of greenhouse gases put into the air from activities you do. The goal is to reduce your carbon footprint by making changes to your habits. Turn off light bulbs and appliances when not in use, and be conscientious about the miles you drive each day. Also buying local, sustainably-grown food reduces transportation emissions and fertilizer use. Reducing water use cuts down on energy use, especially when one limits the amount of hot water used in the home. Lastly, consider eating less meat during the week, as growing livestock takes a lot more energy and water than growing plants.

Reducing use of disposal plastics, like water bottles, is even better than recycling.

What Can Your Classroom and School Do?

Develop Three R's School Program. There are many activities you can use to engage your students in the three R's. Start a classroom or school-wide program each year that challenges individual students or classrooms to compete with each other to reduce their classroom use of materials and classroom waste and to recycle as much as possible. Sometimes people add a fourth *R* to follow: Rot. Ask the school administrators and cafeteria staff if composting could happen at the school, which could then be used to enrich the school grounds.

Great Energy Challenge. Develop a program at school to reduce energy use. Have each classroom develop an energy plan and then monitor the school's energy use across the year. The energy plans might include reminding students to turn off lights when not in use, replacing school light bulbs with energy efficient alternatives, and adjusting classroom temperatures a few degrees.

Develop a List of Local Sustainable Vendors. Have your students develop a list of vendors—shops, restaurants, grocery stores, and markets—that carry locally-grown or locally-made products or companies that have programs to lower their use of fossil fuels. Once your class has created a list, consider asking these vendors to visit your classroom to talk about what they are doing to reduce their carbon footprints.

What Can Your Community Do?

Support Public Transportation. Advocate for efficient public transportation and safe bike trails. If these systems are in place, support them by using them whenever they provide a reasonable alternative to driving a single vehicle.

Get Connected. Get connected to local parks, businesses, and community groups so that you can be part of the programs happening in your local community. Become aware of these options, and learn about what partnerships might be appropriate for your students.

Support Parks and Green Spaces. Support your local parks and green spaces by visiting them often and learning more about how they can use your help. Community greening programs are a great way to participate in community-wide programs or events and to become more educated about local issues. Community greening involves planting native plants, which are an important carbon sink, and one way to improve water drainage as well.

Let Your Voice Be Heard. Investigate ways to get involved in the community or community issues being discussed. As a class, weigh in on the issues. Write a class letter to your local newspaper, create a blog, or make a video about what's important to your classroom.

Buying local food reduces the carbon footprint of your groceries.

In the Classroom

My Carbon Footprint

Carbon footprint activities are one way to help students see how their behaviors and choices influence carbon emissions. There are numerous carbon-footprint calculators available through the Web, but many of these calculators are complicated. Facing the Future developed a middle school climate curriculum that includes a carbon-footprint activity. In the activity, students learn what the carbon footprint is, calculate their footprint, and then compare it to average footprints around the world. Students then develop plans to act in order to decrease their footprint. For the full activity and a free climate-change unit, see Facing the Future: http://www.facingthefuture.org/.

Materials

- My Carbon Footprint worksheet
- Access to Internet and a carbon-footprint calculators: http://calc.zerofootprint.net/youth/ (For a more advanced calculator use U.S. EPA's Household Emissions Calculator: http://www.epa.gov/climatechange/emissions/ind_calculator.html)
- 1 incandescent and 1 compact fluorescent light bulb. These are to be shown to students so they are able to recognize which kind is being used in their homes.

Directions

1. Prior to the lesson, explore carbon-footprint calculators and develop a carbon-footprint worksheet, or use the Facing the Future materials directly (http://www.facingthefuture.org/). The worksheet should ask students to record information about their energy use, transportation, and food choices.
2. Review greenhouse gases (GHGs) and their role on Earth. Explain to students that a carbon-footprint calculator helps people track how much carbon they put into the air. Have students share information from the carbon-footprint worksheets.
3. Direct students to the carbon-footprint calculator and have students input their worksheet data to obtain a carbon-footprint estimate.
4. Then ask students to compare carbon footprints to each other and others around the world. For more information, visit http://www. zerofootprintkids.com.
5. Once students learn about their footprint, they can review and change some of their answers in the calculator and observe the changes in the results.

Ask Your Students

1. Why are the GHG emissions of a person or a business called a "carbon footprint"?
2. In which ways can you reduce your carbon footprint?
3. What did you learn from the carbon-footprint calculator? What actions would be easiest for you to implement to start reducing your carbon footprint?

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Teaching Resources:

California Education and the Environment Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm.

Climate Crisis: http://www.climatecrisis.net/take_action/reduce_your_impact_at_home.php.

EPA's Climate Ready Estuaries Program: http://www.epa.gov/cre/.

The Story of Stuff: http://www.yesmagazine.org/for-teachers/curriculum/the-story-of-stuff-another-way.

Green America: http://www.greenamericatoday.org/.

Glossary

albedo
(al-BEE-doh)
Scientific measurement of the amount of sunlight that is reflected by a surface.

allotrope
(A-loh-trohp)
One of several forms of a chemical element. Not all elements have allotropes.

anthracite
(AN-thruh-sit)
Most valuable type of coal, containing high carbon content. Also called hard coal, black coal, and stone coal.

atmosphere
(AT-muhs-feer)
Layers of gases surrounding a planet or other celestial body.

biofuel
(BI-oh-fyool)
Energy source derived directly from organic matter, such as plants.

biogeochemical cycle
(bi-oh-jee-oh-KEHM-ih-kul SI-kul)
Process by which a chemical, such as carbon, moves between the living and nonliving parts of Earth.

biomass
(BI-oh-mas)
Energy in living organisms.

biosphere
(BI-oh-sfeer)
Part of Earth where life exists.

bituminous
(bih-TOO-mih-nus)
Type of coal containing bitumen, an organic, tar-like substance.

British thermal unit (Btu)
(BRI-tish THEHR-mul YOO-nut)
Amount of heat or energy required to raise the temperature of one pound of water by one degree Fahrenheit, or 251.997 calories.

cap-and-trade
(KAP AND TRAYD)
System for reducing air pollution by placing limits on how much companies can pollute without having to pay for it.

carbon budget
(KAR-bun BUH-jeht)
Total amount of carbon and carbon compounds in Earth and Earth's atmosphere.

carbon flux
(KAR-bun FLUKS)
Relationship between the amount of carbon added to the atmosphere and the amount of carbon removed from the atmosphere.

carbon sink
(KAR-bun SIHNK)
Area or ecosystem that absorbs more carbon dioxide than it releases.

chlorofluorocarbon
(klohr-oh-flohr-oh-KAR-buhn)
Chemical compound mostly used in refrigerants and flame-retardants. Some CFCs have destructive effects on the ozone layer.

climate
(KLI-mut)
All weather conditions for a given location over a period of time.

climate change
(KLI-mut CHAYNJ)
A change in a climate that can be identified (e.g., using statistical tests) by changes in mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. (IPCC)
A change of climate that is attributed directly or indirectly to human activity that alters the composistion of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. (UNFCCC)

climatologist
(kli-muh-TAHL-uh-jist)
Person who studies long-term patterns in weather.

combustion
(kum-BUS-chun)
Burning, or the process of a substance reacting with oxygen to produce heat and light.

coral bleaching
(KOHR-uhl BLEE-ching)
The unhealthy loss of color in corals.

cryosphere
(KRI-uh-sfeer)
Icy part of Earth's water—including icebergs, glaciers, and ice caps.

dendrochronology
(dehn-droh-kruh-NAH-luh-jee)
Study of tree rings and how they can identify and date weather events and changes in the atmosphere.

energy budget
(EH-nur-jee BUH-jeht)
Relationship between the amount of energy taken in by an organism, and the amount of energy used by the organism. Energy budgets are usually measured in calories.

energy portfolio
(EH-nur-jee port-FOH-lee-oh)
Amount of electricity, water, and other energy used by a collection (portfolio) of buildings, rooms, or other specific areas.

feedback loop
(FEED-bak LOOP)
Cycle of causes and effects in which the effects either directly reinforce (in a positive feedback loop) or oppose (in a negative feedback loop) the original condition.

fossil fuels
(FAH-sul FYOOL)
Coal, oil, or natural gas. Fossil fuels form from remains of ancient plants and animals.

geosphere
(JEE-oh-sfeer)
Outer, solid portion of Earth. Also called the lithosphere.

geothermal power
(jee-oh-THUR-mul EH-nur-jee)
Heat energy generated within Earth.

global carbon cycle
(GLOH-bul KAR-bun SI-kul)
Series of processes in which carbon (C) atoms circulate through Earth's land, ocean, atmosphere, and interior.

global radiative balance
(GLOH-bul RAY-dee-uh-tihv BAL-uns)
Relationship between the heat energy from the sun that is absorbed by Earth's atmosphere, and the heat produced by Earth itself.

Greenhouse Effect
(GREEN-hows ih-FEHKT)
Phenomenon in which gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.

greenhouse gas
(GREEN-hows GAS)
Gases in the atmosphere, such as carbon dioxide and ozone, that absorb solar heat reflected by the surface of Earth, warming the atmosphere.

hydrocarbon
(HI-droh-kar-bun)
Chemical compound made entirely of the elements hydrogen and carbon.

hydroelectricity
(hi-droh-ee-lehk-TRIH-sih-tee)
Power generated by converting moving water to electricity. Also called hydroelectric energy or hydroelectric power.

hydrosphere
(HI-droh-sfeer)
All Earth's water—in the ground, on the surface, and in the air.

ice age
(IS AYJ)
Long period of cold climate when glaciers cover large parts of Earth. The last ice age peaked about 20,000 years ago. Also called glacial age.

impermeable
(ihm-PUR-mee-uh-bul)
Not allowing liquids or gasses to pass through.

interglacial period
(ihn-tur-GLAY-shul PEER-ee-ud)
Time between ice ages, when global temperatures are warmer and sea levels rise.

isotope
(I-suh-tohp)
Atom with an unbalanced number of neutrons in its nucleus, giving it a different atomic weight than other atoms of the same element.

Milankovitch cycles
(mih-LAN-koh-vihch SI-kul)
One of three phases that describe changes in Earth's climate based on Earth's rotation around the sun over thousands of years.

mitigation
(mih-tih-GAY-shun)
To lower the severity of a natural or human condition.

net primary production
(NEHT PRI-mair-ee proh-DUK-shun)
Rate at which autotrophs such as plants use carbon dioxide to create energy able to be used by other organisms.

ocean acidification
(OH-shun uh-sih-dih-fih-KAY-shun)
Decrease in the ocean's pH levels, caused primarily by increased carbon dioxide. Ocean acidification threatens corals and shellfish.

ocean conveyor belt
(OH-shun kun-VAY-yur BEHLT)
System in which water moves between the cold depths and warm surface in oceans throughout the world. Also called thermohaline circulation.

ozone hole
(OH-zohn HOHL)
Circular pattern, usually located near the Antarctic, of thin atmospheric ozone, which absorbs harmful ultraviolet sunlight.

ozone layer
(OH-zohn LAY-ur)
Layer in the atmosphere containing the gas ozone, which absorbs most of the sun's ultraviolet radiation.

permafrost
(PUR-muh-frahst)
Permanently frozen layer of Earth's surface.

permeable
(PUR-mee-uh-bul)
Allowing liquid and gases to pass through.

photosynthesis
(foh-toh-SIHN-theh-sihs)
Process by which plants turn water, sunlight, and carbon dioxide into water, oxygen, and simple sugars.

photovoltaic
(foh-toh-vawl-TAY-ihk)
Able to produce energy when exposed to light.

primary productivity
(PRI-mair-ee proh-duk-TIH-vuh-tee)
Rate at which autotrophs such as plants use solar or chemical energy to grow and create new life.

proxy data
(PRAHK-see DAY-tuh)
Non-climate information, such as ice cores or tree rings, analyzed for clues about climate from hundreds or millions of years ago.

salinity
(say-LIH-nih-tee)
Saltiness.

sustainable
(suh-STAIN-uh-bul)
Able to continue at the same rate for a long time.

trophic level
(TROH-fihk LEH-vul)
One of three positions on the food chain: autotrophs (first), herbivores (second), and carnivores and omnivores (third).

weather
(WEH-thur)
State of the atmosphere, including temperature, atmospheric pressure, wind, humidity, precipitation, and cloudiness.

Facilitator Questions

Chapter 1

Student Thinking: Climate and Weather

1. What conditions occur in your region that may confuse students about weather and climate? What experiences might your students bring to the classroom because of these conditions?
2. What are ways you can help students differentiate between weather and climate?
3. In what ways might contrasting weather and climate help students better understand climate change?

Student Thinking: Greenhouse Gases

1. What would you predict your students would say in response to a question about greenhouse gases and the Greenhouse Effect?
2. Which of the four responses do you believe to be the most sophisticated, and why?
3. How would your instruction change in response to Sarah as compared to Joyce?
4. What information or experiences do these students need in order to improve their understanding of the topic?

Pictures of Practice: Greenhouse Gases: Good or Bad?

1. Emily thinks the Greenhouse Effect and greenhouse gases are bad and is confusing the Greenhouse Effect with amplified warming. What strategies would you use to respond to Emily?
2. Christopher believes greenhouse gases are good because they benefit plants. How would you adjust instruction to help Christopher build on his understanding?
3. Eliazar remains uncertain even after discussion of greenhouse gases. How would you respond to Eliazar's confusion? What additional activities would help Eliazar understand these concepts?

Pictures of Practice: Greenhouse Gases and the Ozone Hole

1. Why do you think students confuse the ozone hole and climate change? How can you use this information to inform your instructional plans?
2. If students in your classroom were confusing the two, how would you respond?
3. Think about the trade-offs of the greenhouse analogy. How is it helpful? What are potential drawbacks for students?

Chapter 2

Student Thinking: Confusion About Plants and Climate

1. Order the previous responses from least to most sophisticated. How did you determine your order?
2. How might you respond to Casey's statement if she were in your class? How might you respond to Dante's?
3. What other relationships might you want your students to identify with respect to cutting down trees and climate change? How might you help your students learn these relationships?

Pictures of Practice: Trees and Climate Change

1. All three sixth-grade students see a connection to carbon dioxide, but their explanations are not completely correct. How would you reteach this concept to these students?
2. What do you think Emily means by "purifies our air"?

3. The eighth graders focus on plants making oxygen. Why do you think this idea is common among students? How would you respond in your instructional plans?
4. Both Ian and Marc are in the same eighth-grade classroom but have very different levels of understanding about this concept. How would your instruction be different when responding to each?

Student Thinking: Transformation of Carbon

1. What are ways to assess your students' ideas about what happens to food once it is eaten? Why is an understanding important for understanding carbon cycling?
2. How would you help students create a story about where carbon goes as it moves through the food chain?
3. Biomass is an important reservoir for storing carbon. How can you connect this concept to climate change?

Student Thinking: Burning Gasoline

1. Order these responses from least to most sophisticated. How did you determine the order?
2. All of these students are from the same seventh-grade classroom. How would your instruction change if you were working with Maria as compared to Karin?
3. How are Darian's ideas similar to Karin's? How are they different?
4. How would you help a student such as Jessie reach an understanding like Karin's?

Pictures of Practice: Combustion and Carbon Dioxide

1. What does the word *burning* mean to a sixth-grade student such as Alan? How can you move student thinking from a focus on the action of the flame to a chemical process that changes materials?
2. How can you help Alan build on what he knows about the burning process?
3. Eliazar describes carbon dioxide as the same thing as energy. How would you respond to Eliazar's misconception?
4. Like smoke and exhaust, Emily describes gasoline burning "kind of like a gas" that's bad for the car. How can you help Emily better understand the gases given off by the cars?

Chapter 3

Student Thinking: What Are Fossil Fuels?

1. What patterns do you notice in student responses before the instruction? What do you think causes students to develop these ideas about fossil fuels?
2. In what ways do students make progress in their explanations of fossil fuels?
3. What remaining gaps or misunderstandings do students retain after the instruction?

Pictures of Practice: Fossil Fuels and Carbon

1. Eliazar describes fossil fuels as coming from dinosaurs and taking three hours to form. What would be your next step as Eliazar's teacher?
2. Students struggle with large numbers and long time. How can you help students better understand the time span that it takes for fossil fuels to form?
3. Alan says that fossil fuels are made of carbon that "mixes and grows stronger." What do you think Alan means? How would you respond to Alan's explanation?

Pictures of Practice: A Burning Candle

1. While the candle burns, Ms. Walker and students discuss the flame of the burning candle. Amaya explains the candle releases CO_2 caused by the flame. What do you think she means?
2. Samantha explains that "only a little bit will become a gas." What would be your next step if Samantha shared this in your classroom?
3. Alan's final explanation of combustion follows. Look closely at what Alan describes. What ideas does he understand, and where does he need additional help?
4. Alan: Burning the candle is like burning gasoline in the car because it has the same effect. It's still making carbon dioxide go into the air and it's making energy, but just that we're not using the energy so it's just...it has no where to go except into the air and the atmosphere.

Chapter 4

Student Thinking: The Mauna Loa Graph

1. Order students' answers from least to most sophisticated. How did you determine your order?
2. Emily and Samantha sit next to each other in class. Compare their answers. How would your teaching differ depending on which student you were working with?
3. What does Burhon mean by "polluted gas"? Where do you think he developed this idea?
4. What do you think Xena means by "use more carbon dioxide"?
5. What do you think Marc means by "bad gases"?

Pictures of Practice: Mauna Loa Carbon-Dioxide Records

1. Compare the sixth-grade responses to the eighth-grade responses. How are they different?
2. If you were teaching the eighth-grade students, how would you design lessons to help them develop a better explanation of the Mauna Loa graph?
3. Samantha says that we use a lot of energy, and it goes up into the atmosphere. What is Samantha misunderstanding? How would you respond to Samantha if she shared this in your classroom?

Pictures of Practice: Evidence of Past Climate Change

1. Marc describes the gases as *fizz,* but cannot name any gases that make up the *fizz.* He uses his experience of soda carbonation to explain what he heard. How would you reteach ice cores so Marc better understands the gases found in ice cores and what they mean?
2. Burhon describes the layers of ice as a record of an ice age and weather. What does Burhon misunderstand between *climate* and *weather*?
3. The most important idea that students should learn in studying ice cores is that gases found in ice cores tell us about climate in our past (especially oxygen isotopes and levels of trace gases like carbon dioxide). Think about how you would reteach so that students can use this information to explain climate change?

Chapter 5

Student Thinking: Climate and the Ocean

1. Many student ideas are black or white. For example, students may believe if temperatures warm, all the animals will die. However, not all animals will die. In fact, some may flourish. Think about patterns under the Common Student Ideas column, and how you would help students move beyond black-or-white thinking.
2. What are real-life examples you could use to help students with these concepts?

Student Thinking: Ice and Climate Change

1. Why do you think students believe polar bears and penguins live in the same area? How would you respond if a student mentioned this in your classroom?
2. How would you help students understand an abstract concept such as the North Pole, especially given that the Arctic Ocean is mostly sea ice?
3. What concepts would you focus on with respect to melting ice and climate change? What do you believe is most important for students to learn, and why?

Pictures of Practice: Melting Ice

1. The impacts of climate change are uncertain. If you were teaching about potential impacts of climate change on our ocean, how would you teach about uncertainty, especially with respect to melting ice?
2. In order to understand the difference in melting sea ice from the Arctic and melting ice on land in Antarctica and Greenland, students must understand basic concepts about volume and density. How would you help students apply these concepts to melting ice and climate change?
3. Burhon is concerned that water and inland climates will change faster than we can adapt. How can you incorporate scenarios for adaptation in your instructional plans?
4. What do you think Hailey means by "a lake might come down and overflow"? What would be your next step to help Hailey improve her understanding?

Pictures of Practice: Surviving Climate Change

1. Ian says polar bears and Arctic fish would need to adapt really fast or go extinct. What does Ian not understand about adaptations and natural selection? How would you reteach so that Ian develops a better understanding of these concepts?
2. Students describe plants as adapted because of ancestor plants. What do you think students mean?
3. Marc says the polar bears would need to lose fur in order to survive. What does Marc not understand about adaptations? If Marc mentioned this in your classroom, what would be your next step?

Chapter 6

Pictures of Practice: Climate Action

1. Students propose impractical (old-fashioned) solutions. How would you respond?
2. Students may give solutions that are idealistic. How can you validate their ideas while helping them see trade-offs of different solutions (no one solution will work for everyone)?
3. Often students may feel they do not have a choice or an impact. How would you help students understand that small actions they take can make a big difference when aggregated?
4. What activities in class or information do you believe will compel students to act—even to take small actions at home?

Pictures of Practice: Our Different Carbon Footprints

1. Carbon footprints are calculated with many "hidden" factors, such as the food one eats or products one buys. How can you introduce these hidden factors to students?
2. Ms. Walker uses milk as an example of a hidden contributor to students' carbon footprint. Focusing on a single common item helps communicate the hidden costs, but what would be your next step for teaching students the larger picture and practical solutions for changing their consumer choices?
3. Not all students have experience with families outside the country, so how would you help students understand why different countries have different carbon footprints?

Student Thinking: Renewable Resources

1. What are ways you might teach trade-offs of renewable resources without making students feel that there is no solution to our energy problems?
2. Are there specific renewable resources that your students are familiar with from their community that you can incorporate into your lesson?
3. How do you think misconceptions about renewable resources being "good" and nonrenewable being "bad" come about? Instead of categorizing things as good or bad, what should students understand?

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 3				
Social Studies	3.1.2	Trace the ways in which people have used the resources of the local region and modified the physical environment.	The Geography of Where We Live (e.g., California Connections: California Natural Regions (pg 42-47 Ocean & Coast)	Chapter 3, 5, 6
	3.3.3	Trace why their community was established, how individuals and families contributed to its founding and development, and how the community has changed over time, drawing on maps, photographs, oral histories, letters, newspapers, and other primary sources.		Chapter 6
	3.4.1	Determine the reasons for rules, laws, and the U.S. Constitution; the role of citizenship in the promotion of rules and laws; and the consequences for people who violate rules and laws.		Chapter 6
	3.4.2	Discuss the importance of public virtue and the role of citizens, including how to participate in a classroom, in the community, and in civic life.		Chapter 6
	3.5.1	Describe the ways in which local producers have used and are using natural resources, human resources, and capital resources to produce goods and services in the past and the present.	California Economy—Natural Choices	Chapter 3, 5, 6
	3.5.2	Understand that some goods are made locally, some elsewhere in the United States, and some abroad.	California Economy—Natural Choices	Chapter 3, 5, 6
	3.5.3	Understand that individual economic choices involve trade-offs and the evaluation of benefits and costs.	California Economy—Natural Choices	Chapter 3, 5, 6
Science	3.1.a	Students know energy comes from the Sun to Earth in the form of light.		Chapter 1
	3.1.b	Students know sources of stored energy take many forms, such as food, fuel, and batteries.		Chapter 2
	3.2.b	Students know light is reflected from mirrors and other surfaces.		Chapter 1
	3.3.a	Students know plants and animals have structures that serve different functions in growth, survival, and reproduction	Structures for Survival in a Healthy Ecosystem	Chapter 5
	3.3.b	Students know in different environments, such as oceans, deserts, tundra, forests, grasslands, and wetlands.		Chapter 5
	3.3.c	Students know living things cause changes inexamples of diverse life forms the environment in which they live: some of these changes are detrimental to the organism or other organisms, and some are beneficial.	Living Things in Changing Environments (e.g., California Connections: Sweetwater Marsh National Wildlife Refuge)	Chapter 5
	3.3.d	Students know when the environment changes, some plants and animals survive and reproduce; others die or move to new locations.	Living Things in Changing Environments (e.g., California Connections: Sweetwater Marsh National Wildlife Refuge)	Chapter 5
	3.3.e	Students know that some kinds of organisms that once lived on Earth have completely disappeared.		Chapter 5
Grade 4				
Social Studies	4.1.3	Identify the state capital and describe the various regions of California, including how their characteristics and physical environments (e.g., water, landforms, vegetation, climate) affect human activity.	Reflections of Where We Live	Chapter 2, 5, 6
	4.1.5	Use maps, charts, and pictures to describe how communities in California vary in land use, vegetation, wildlife, climate, population density, architecture, services, and transportation.	Reflections of Where We Live	Chapter 2, 3, 6

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 4 continued				
Social Studies	4.4.6	Describe the development and locations of new industries since the turn of the century, such as the aerospace industry, electronics industry, large-scale commercial agriculture and irrigation projects, the oil and automobile industries, communications and defense industries, and important trade links with the Pacific Basin.		Chapter 6
	4.5.3	Describe the similarities (e.g., written documents, rule of law, consent of the governed, three separate branches) and differences (e.g., scope of jurisdiction, limits on government powers, use of the military) among federal, state, and local governments.		Chapter 6
Science	4.2.a	Students know plants are the primary source of matter and energy entering most food chains.	Plants: The Ultimate Energy Resource	Chapter 2
	4.2.b	Students know producers and consumers (herbivores, carnivores, omnivores, and decomposers) are related in food chains and food webs and may compete with each other for resources in an ecosystem.	The Flow of Energy Through Ecosystems	Chapter 2
	4.2.c	Students know decomposers, including many fungi, insects, and microorganisms, recycle matter from dead plants and animals.	Life and Death With Decomposers	Chapter 2
	4.3.b	Students know that in any particular environment, some kinds of plants and animals survive well, some survive less well, and some cannot survive at all.		Chapter 5
	4.6	Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations.		Chapter 4, 5
Grade 5				
Social Studies	5.1.1	Describe how geography and climate influenced the way various nations lived and adjusted to the natural environment, including locations of villages, the distinct structures that they built, and how they obtained food, clothing, tools, and utensils.		Chapter 4
	5.7.3	Understand the fundamental principles of American constitutional democracy, including how the government derives its power from the people and the primacy of individual liberty.		Chapter 6
Science	5.1.h	Students know living organisms and most materials are composed of just a few elements.		Chapter 2
	5.2.e	Students know how sugar, water, and minerals are transported in a vascular plant.		Chapter 2
	5.2.f	Students know plants use carbon dioxide (CO^2) and energy from sunlight to build molecules of sugar and release oxygen.		Chapter 2, 4
	5.2.g	Students know plant and animal cells break down sugar to obtain energy, a process resulting in carbon dioxide (CO2) and water (respiration).		Chapter 2
	5.3.d	Students know that the amount of freshwater located in rivers, lakes, underground sources, and glaciers is limited and that its availability can be extended by recycling and decreasing the use of water.	Our Water: Sources and Uses	Chapter 5
	5.3.e	Students know the origin of the water used by their local communities.		Chapter 5
	5.4.a	Students know uneven heating of Earth causes air movements (convection currents).		Chapter 1

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 5 continued				
Science	5.4.c	Students know the causes and effects of different types of severe weather.		Chapter 1
	5.4.d	Students know that weather forecasts depend on many variables.		Chapter 1
	5.6	Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations.		Chapter 4, 5
Grade 6				
Social Studies	6.1.3	Discuss the climatic changes and human modifications of the physical environment that gave rise to the domestication of plants and animals and new sources of clothing and shelter.		Chapter 2, 4
	6.2.2	Trace the development of agricultural techniques that permitted the production of economic surplus and the emergence of cities as centers of culture and power.	Agricultural Advances in Ancient Civilizations	Chapter 5
Science	6.2.c	Students know beaches are dynamic systems in which the sand is supplied by rivers and moved along the coast by the action of waves.		Chapter 5
	6.3.b	Students know that when fuel is consumed, most of the energy released becomes heat energy.		Chapter 3
	6.3.d	Students know heat energy is also transferred between objects by radiation (radiation can travel through space).		Chapter 1
	6.4.a	Students know the sun is the major source of energy for phenomena on Earth's surface; it powers winds, ocean currents, and the water cycle.		Chapter 1
	6.4.b	Students know solar energy reaches Earth through radiation.		Chapter 1
	6.4.d	Students know convection currents distribute heat in the atmosphere and oceans.		Chapter 1
	6.4.e	Students know differences in pressure, heat, air movement, and humidity result in changes of weather.		Chapter 1
	6.5.a	Students know energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis and then from organism to organism through food webs.		Chapter 2
	6.5.b	Students know matter is transferred over time from one organism to others in the food web and between organisms and the physical environment		Chapter 2
	6.5.e	Students know the number and types of organisms an ecosystem can support depends on the resources available and on abiotic factors, such as quantities of light and water, a range of temperatures, and soil composition.		Chapter 5
	6.6.a	Students know the utility of energy sources is determined by factors that are involved in converting these sources to useful forms and the consequences of the conversion process.	Energy: It's Not All the Same to You!	Chapter 3
	6.6.b	Students know different natural energy and material resources, including air, soil, rocks, minerals, petroleum, freshwater, wildlife, and forests, and know how to classify them as renewable or nonrenewable.	Energy and Material Resources: Renewable or Not?	Chapter 3
	6.6.c	Students know the natural origin of the materials used to make common objects.	Made From Earth: How Natural Resources Become Things We Use	Chapter 3
	6.7	Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations.		Chapter 4, 5

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 7				
Science	7.1.d	Students know that mitochondria liberate energy for the work that cells do and that chloroplasts capture sunlight energy for photosynthesis.		Chapter 2
	7.3.a	Students know both genetic variation and environmental factors are causes of evolution and diversity of organisms.	Shaping Natural Systems Through Evolution	Chapter 5
	7.3.e	Students know that extinction of a species occurs when the environment changes and that the adaptive characteristics of a species are insufficient for its survival.	Responding to Environmental Change	Chapter 5
	7.4.e	Students know fossils provide evidence of how life and environmental conditions have changed.		Chapter 4
	7.4.g	Students know how to explain significant developments and extinctions of plant and animal life on the geologic time scale.	Extinction: Past and Present	Chapter 4
	7.6.a	Students know visible light is a small band within a very broad electromagnetic spectrum.		Chapter 1
	7.6.f	Students know light can be reflected, refracted, transmitted, and absorbed by matter.		Chapter 1
	7.7	Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations.		Chapter 4, 5
Grade 8				
Social Studies	8.3.6	Describe the basic law-making process and how the Constitution provides numerous opportunities for citizens to participate in the political process and to monitor and influence government (e.g., function of elections, political parties, interest groups).		Chapter 6
	8.6.1	Discuss the influence of industrialization and technological developments on the region, including human modification of the landscape and how physical geography shaped human actions (e.g., growth of cities, deforestation, farming, mineral extraction).		Chapter 3
	8.12.1	Trace patterns of agricultural and industrial development as they relate to climate, use of natural resources, markets, and trade and locate such development on a map	Agricultural and Industrial Development in the United States (1877—1914)	Chapter 2, 3, 5, 6
Science	8.12.5	Examine the location and effects of urbanization, renewed immigration, and industrialization (e.g., the effects on social fabric of cities, wealth and economic opportunity, the conservation movement).	Industrialization, Urbanization, and the Conservation Movement	Chapter 2, 3, 5
	8.6.a	Students know that carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organisms.		Chapter 2
	8.6.b	Students know that living organisms are made of molecules consisting largely of carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.		Chapter 2
	8.6.c	Students know that living organisms have many different kinds of molecules, including small ones, such as water and salt, and very large ones, such as carbohydrates, fats, proteins, and DNA.		Chapter 2
	8.9	Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations.		Chapter 4, 5

Credits

Editing Credits

Instructional Editor	Lindsey Mohan, Ph.D. / National Geographic Society
	Kristin M. Dell, B.A. / National Geographic Society
Copy Editor	Kate Matracia / NounSense

Design Credits

Art Direction and Design	Cindy Olson

Content and Educational Writers

EEI Introduction	Kristin M. Dell, B.A.
Climate Introduction	Marcia S. Matz, M.A.
Chapter 1	Lindsey Mohan, Ph.D.
	Jenny D. Ingber, Ph.D.
Chapter 2	Lindsey Mohan, Ph.D.
	Jenny D. Ingber, Ph.D.
Chapter 3	Nicole D. LaDue, M.A.T
	Lindsey Mohan, Ph.D.
Chapter 4	Nicole D. LaDue, M.A.T
	Lindsey Mohan, Ph.D.
Chapter 5	Tara G. Treiber, B.A.
Chapter 6	Jose Marcos-Iga, Ph.D.
	Tania T. Hinojosa, M.E.T.

Content and Educational Reviewers

Reviewers	Jenny D. Ingber, Ph.D.
	LuAnn Dahlman, B.S.
	Tara G. Treiber, B.A. / Heal the Bay
	Catie Boarts, M.A. / Heal the Bay
	Kristin M. Dell, B.A. / National Geographic Society

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Director and Producer	Lindsey Mohan / National Geographic Society
Associate Producer	Alison Michel / National Geographic Society
Videographers	Laleh Soomekh
	Kathy Huang / Kathy Huang Films
Production Sound Mixer	Don Hale / Don Hale Production Sound
Editor	Rachel Dwiggins / National Geographic Society
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(Students study life in water on Potomac River)

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