Project Learning Tree®
Secondary Environmental Education Module

SOUTHEASTERN FORESTS AND CLIMATE CHANGE

PINEMAP

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SOUTHEASTERN FORESTS AND CLIMATE CHANGE

Project Learning Tree®

PINEMAP

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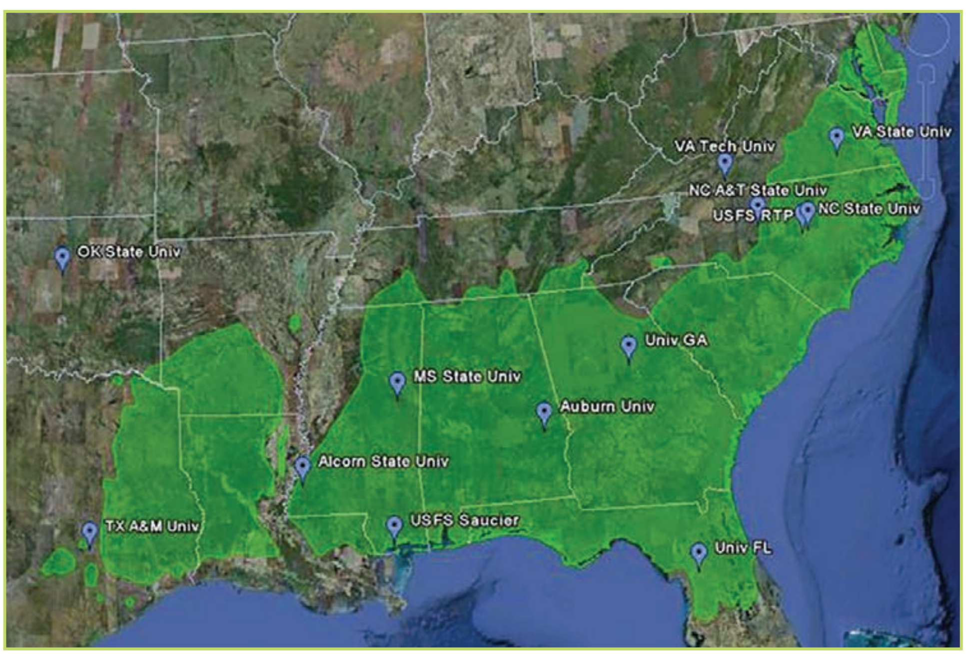
BACKGROUND

Southeastern Forests and Climate Change

About PINEMAP

THE PINE INTEGRATED NETWORK: EDUCATION, MITIGATION, AND ADAPTATION PROJECT (PINEMAP) is one of three Coordinated Agriculture Projects (CAP) awarded by the United States Department of Agriculture (USDA), National Institute of Food and Agriculture (NIFA) in 2011. The purpose of these CAPs is to encourage agriculture and forestry producers to increase carbon sequestration and adapt practices to reduce the impact of anticipated climate variation. These initiatives have created opportunities for the development of new insights and solutions to the challenges of climate change. PINEMAP focuses on planted pine forests in the Atlantic and Gulf coastal states that are managed by ***industrial*** and ***non-industrial*** private landowners (figure 1). Loblolly pine (*Pinus taeda*) accounts for 80 percent of the planted forests in the Southeast United States (U.S.). PINEMAP integrates research, Extension, and education to enable landowners to manage forests to increase carbon sequestration, increase efficiency of nitrogen and other fertilizer inputs, and adapt forest management approaches to increase forest resilience and sustainability under variable climates. Eleven land-grant universities, the U.S. Forest



REMOTE SENSING IMAGE FROM GOOGLE EARTH; RANGE MAP FROM U.S. FOREST SERVICE.

Figure 1. PINEMAP focuses on the native range of loblolly pine (shown in green) and includes thirteen collaborating institutions (shown in blue).

Service, state climatologists, and Project Learning Tree® (PLT) are collaborating in PINEMAP activities.

Rather than research that focuses on a small or theoretical question, PINEMAP research is focused on an applied question: how can we continue to grow pine trees in the face of climatic change, and in a way that mitigates climate changes? There are many ways to answer that question, and they are all linked together. For example, if tree breeding results in shuffling the genetic makeup of trees, a new generation might thrive in the changing environment. This will depend upon many things, such as how the forests are managed, when fertilizer is applied, and how much rainfall arrives. Researchers have amassed additional climate data and created a new computer-based climate model that is able to downscale regional projections to the county level, allowing landowners to think about the range of realistic possibilities for the future. But climate change models also depend on the level of carbon emissions and the ways we choose to sequester carbon, so exact forecasts are not possible. The sequestration power of trees is not limited to merely planting them, but also to using them in long-lived wood products. These interconnected questions and answers have their roots in tree physiology, economics, genetics, and ecology. Over 100 faculty, staff, and student researchers investigated aspects of these questions as part of PINEMAP from 2011-2016, working toward the following outcomes:

- Increased carbon (C) sequestration from silvicultural and genetic enhancement of productivity and efficiency of fertilizer use, and resilience to climate variability and disturbance.
- A more robust and resilient forest-based economy in the Southeast U.S.
- Enhanced connections between corporate and noncorporate forest landowners and forestry and climate researchers and education and outreach professionals.
- Enhanced capacity for regional, interdisciplinary collaboration among climate and forest scientists and Extension and education professionals.
- Public policy that supports sustainable management of planted pine under future climate scenarios.
- Engaged and literate public with the capacity to make informed, practical decisions related to climate, forest ecosystems, and forest management.

One way PINEMAP accomplishes its education-related outcomes is to work closely with Project Learning Tree to develop, test,

Over 100 faculty, staff, and student researchers are helping to achieve PINEMAP's outcomes by integrating research, extension, and education programs.

U.S. FOREST SERVICE

and implement this module. Forest researchers have helped develop and review these activities to reflect concepts they are currently exploring. Although some examples relate to loblolly pine, the activities and concepts can be easily applied to forests across the continent. Teachers who use this material will be able to help their students gain the foundational concepts that underpin current climate science and forestry research.

Project Learning Tree uses the forest as a "window on the world."

Visit www.pinemap.org for project updates, annual reports with research results, publications, and more.

About Project Learning Tree

Project Learning Tree® (PLT) is widely recognized as one of the premier environmental education programs in the world. PLT develops students' awareness, knowledge, and appreciation of the environment, builds their skills and ability to make informed decisions, and encourages them to take personal responsibility for sustaining the environment and our quality of life that depends on it.

PLT provides educators with high-quality professional development and hands-on activities to help bring the environment into classrooms and students into the environment. PLT teaches children how to think—not what to think—about complex environmental issues and helps develop students' critical thinking and problem-solving skills. For more information, visit https://www.plt.org.

PLT is an initiative of the Sustainable Forestry Initiative Inc., a sustainability leader that stands for future forests. Through PLT and other initiatives, SFI supports getting youth outdoors and into nature in ways that inspire them to become environmental stewards and future forest leaders, and to introduce them to green careers. For more information, visit www.sfiprogram.org.

What Is Environmental Education?

The PLT program consists of three essential elements:

- High-quality curriculum materials
- Diverse network of professional educators and natural resource specialists
- Professional development delivery system

PLT's professional development consists of carefully designed in-person workshops, online courses, and blended trainings that are customized for specific grade levels, topics, and teaching situations. More than 20,000 educators attend PLT workshops annually to learn how to integrate environmental and sustainability education into their teaching and become comfortable teaching outdoors—in urban, suburban, and rural environments.

PLT was one of the first environmental education programs in the U.S. to establish a protocol of professional development as part of its methodology. PLT's comprehensive system of delivering curriculum materials to educators in conjunction with professional development helps ensure the materials are used most effectively with students.

PLT's instructional materials can be easily integrated into lesson plans for all grades and subject areas to help teach youth about trees, forests, and the environment. Topics include forests, wildlife, water, air, energy, waste, climate change, invasive species, biotechnology, biodiversity, community planning, and more! All of PLT's multi-disciplinary supplemental curriculum and grade-specific lesson plans are practical, hands-on, and fun – and aligned with state and national academic standards, including Common Core State Standards and Next Generation Science Standards (NGSS).

Visit www.plt.org for details about the correlations between PLT activities and your state's academic standards.

PLT's network provides educators with customized professional development, state-specific supplements to PLT's educational materials that address the local environment, and personalized assistance for incorporating environmental education and outdoor learning into your classroom, including connections to mentor teachers, community members, and natural resource professionals.

Because all PLT programs are directed and implemented locally, this not only facilitates adaptations to meet local needs, but the programs also provide opportunities for local investigations and service-learning projects.

PLT's GreenSchools program inspires students to apply STEM (science, technology, engineering, math) and investigative skills to make their school more green and healthy.

PLT's GreenWorks! grants support student-led action projects. Students learn they can make a difference in the world as they are empowered to make changes and take ownership of projects they lead to improve their school or an aspect of their community's environment.

For more information and resources, visit www.plt.org. Contact your state's PLT Coordinator for local support, sign up to receive PLT's e-newsletter, The Branch, and join PLT on social media.

What Is Environmental Education?

Environmental education is a process that increases the learner's awareness and knowledge about the environment and related issues. Environmental education enhances critical-thinking, problem-solving, and decision-making skills by teaching individuals to understand various sides of an environmental issue and to make informed and responsible decisions concerning the environment and related issues (UNESCO, 1978). Environmental education does not advocate a particular viewpoint or course of action (U.S. EPA, 1997).

The three objectives of environmental education as they are written in the Tbilisi Declaration, one of the founding documents of the environmental education field, are to (1) foster clear awareness of and concern about economic, social, political, and ecological interdependence in urban and rural areas; (2) provide every person with opportunities to acquire the knowledge, values, attitudes, commitment, and skills needed to protect and improve the environment; and (3) create new patterns of behavior of individuals, groups, and society as a whole toward the environment.

Environmental education enhances critical-thinking, problem-solving, and decision-making skills.

PLT Mission, Vision, and Goals

Mission: PLT advances environmental literacy and promotes stewardship through excellence in environmental education, professional development, and curriculum resources that use trees and forests as windows on the world.

Vision: PLT is committed to creating a future where the next generation values the natural world and has the knowledge and skills necessary to make informed decisions and take responsible actions to sustain forests and the broader environment.

PLT uses the forest as a "window on the world" to increase students' understa-nding of our complex environment, to stimulate critical and creative thinking, to develop the ability to make informed decisions on environmental issues, and to instill the confidence and commitment to take responsible action on behalf of the environment.

The goals of PLT are to

1. provide students with awareness, appreciation, understanding, skills, and commitment to address environmental issues;
2. enable students to apply scientific processes and higher-order thinking skills to resolve environmental problems;
3. help students acquire an appreciation for and tolerance of diverse viewpoints on environmental issues and develop attitudes and actions based on analysis and evaluation of the available information;
4. encourage creativity, originality, and flexibility to resolve environm-ental problems and issues; and
5. inspire and empower students to become responsible, productive, and participatory members of society.

Project Learning Tree produces high-quality environmental education materials to help educators teach about natural and built environments.

LARRY KORHNAK, UNIVERSITY OF FLORIDA

Pine forests in the Southeast play an important role in the region by providing both environmental and economic benefits.

Why Focus on Southeastern Forests and Climate Change?

Climate change has been identified as the single biggest challenge that faces the planet today, but not everyone is aware of that and some people don't agree. Perhaps more than any other environmental issue, the topic of climate change challenges science teachers to accurately convey the data, reveal the assumptions, engage critical-thinking skills, and help students understand why there are various opinions across the American public. In addition, the complexity and scale of climate change make it difficult for students to contemplate how they might make a difference. This module provides activities and resources to help educators meet these challenges.

Elected officials, businesses, and citizens in many nations are already planning for climate change. They may be altering their dependence on fossil fuels, redirecting stormwater drainage patterns to accommodate sea level rise, or planting crops that tolerate warmer or more variable growing seasons. Many communities in the United States are also exploring ways to reduce greenhouse gas emissions or respond to sea level rise too. We believe that students and their parents need to acquire current information; the background to make sense out of existing data; the willingness to listen to different points of view; and the skills to work together to help families, neighborhoods, communities, municipalities, states, and nations approach the challenges that climate change may generate.

While a global issue, with many examples of change occurring at the poles, in the oceans, and on mountaintops, climate change is more meaningful to students when examples of impacts are local. Because the impacts of climate change will be different throughout the world, we provide information in this module about the southeastern United States and forest ecosystems to help make the materials relevant. In addition, unique characteristics of specific geographic locations can affect climate change. For example, weather patterns in the Southeast are strongly influenced by the Atlantic Ocean, the Gulf of Mexico, and the El Niño-Southern Oscillation (ENSO), making specific impacts of climate change challenging to project. Unfortunately, most climate models cannot provide exact answers to the simple question about what will happen at a specific place.

The module activities build on basic concepts about climate, forest carbon cycle, forest ecosystems, and genetics.

Although there are many resources available to teach students about the physics of climate change, they are best suited to Earth science courses. This module has been created for biology, agriculture, and environmental science teachers and focuses on the impacts of climate change on forest ecosystems and the role of forests in reducing atmospheric carbon dioxide. Learning about changes in temperature alone may not be meaningful to students, since human beings tolerate wide shifts in temperature daily and seasonally. However, the potential impacts to the ecosystems that students live near and depend upon could be significant, such as crops that no longer thrive in changing plant zones or an increase in the frequency and severity of wildfires. These and other possible effects make the concepts presented in this module relevant to students and educators.

Pine forests in the Southeast provide critical economic and ecological services to U.S. citizens. Forests in this region contain one-third of the contiguous U.S. forest carbon (Jose, 2007). Since 1986, southeastern forests have produced more timber than any other country in the world, and in 2009 more than 1 million jobs and $51 billion in employee compensation were attributed to the Southeast's wood-related industries (Wear & Greis, 2012). It is a commodity that requires time to mature—in some cases 20 to 30 years before harvest. Seedlings that landowners plant this year will grow to be forests that are exposed to the climate of the future. This module helps students understand the challenges and opportunities landowners might consider as they plant and manage their forests.

Students in our pilot tests and teachers responding to our needs assessment have made it clear that they want to know what they can do to affect this issue. Many other resources provide excellent ideas about energy conservation and fossil fuel reduction, all of which are useful to mitigate climate change. Since this module focuses on forests, we provide information about life cycle assessment and the opportunities for consumers to use wood products in order to reduce carbon in the atmosphere. Our pilot tests also suggest that this combination of research-based information and strategies to approach challenges help empower students with knowledge, skills, and a hopeful outlook for their futures.

Purpose of This Module

This module is based on the interdisciplinary research that is conducted through PINEMAP to help understand how forest management can mitigate climate change and adapt to potential changes in temperature, precipitation, and other variables. Activities in this module provide examples that build on basic concepts about climate, forest carbon cycle, forest ecosystems, and genetics. In addition, it introduces computer modeling and life cycle assessment to help students build a sufficiently complex mental model to see the connections between economic, biological, and physical systems. Faculty and graduate students at land-grant universities across the Southeast have contributed to and reviewed these activities, and they have even created videos about their research findings that teachers can download from the module website (https://sfcc.plt.org). Although we have emphasized southeastern forest species and silviculture, the concepts conveyed through these lessons are true in other areas of the United States and across the globe.

The complexity of climate change suggests an opportunity for science teachers to

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Teachers at a workshop use science and math skills to complete calculations to determine the amount of carbon stored in a tree, one of the many activities that support STEM education.

emphasize systems thinking skills and STEM (science, technology, engineering, and math) subjects. Systems thinking refers to a set of critical-thinking skills that helps students understand complex phenomena. Teaching students to see systems and the relationships between elements can enable them to understand the interactions among items that at first blush might not be obviously related, such as wildfire and climate change. Systems thinking skills include recognizing complex relationships, identifying feedback, understanding dynamic behavior, and differentiating stocks and flows. These skills can be extremely helpful to students not only for understanding the behavior of the complex systems covered in this module, but for making the cross-disciplinary connections necessary for students to understand the ecological, economic, and social impacts of most environmental issues. Evidence of the importance of systems thinking skills can be seen in the crosscutting concepts included in the Next Generation Science Standards (NGSS). While only one of the seven crosscutting concepts—system and system models—refers specifically to systems, the other six concepts are commonly covered in systems thinking literature and curricula. On the module website, we provide a table that links the module activities to the NGSS crosscutting concept and its corresponding systems think-ing concept (https://sfcc.plt.org/wp-content/uploads/sites/3/CCNGSS.pdf).

This module includes several tools for instructors interested in encouraging students to apply systems thinking to these activities. In each activity, a **Systems Thinking Connection** box and systems reflection questions help instructors emphasize and reinforce systems concepts. In addition, Activities 1, 2, 3, 5, and 10 include descriptions of **Systems Enrichment Exercises** that are available on the module website. These supplemental exercises provide opportunities to explore systems thinking tools and concepts in more depth. Each systems thinking compo-nent is marked with the systems icon.

Similarly, these activities support STEM education by linking closely with principles that underpin science and technology. From the carbon cycle to genetic breeding trials, students learn to apply science to current

By clicking on the Explore Module Activities tab on the module website, you can find slide presentations, handouts, videos, and answer keys to enhance the activities (https://sfcc.plt.org).

challenges and explore potential solutions to mitigate or adapt to climate change. Computer models and databases can be accessed through websites that bring the technology used by researchers into your classrooms. Processes from the world of production, from cracking hydrocarbons to casting aluminum, introduce engineering concepts through life cycle assessments. And challenges requiring students to make sense out of data, from measuring trees to interpreting a graph, help students improve skills in mathematics. In support of Common Core standards, these activities also enable students to practice critical thinking and writing skills.

This module provides educators with a great deal of background information and resources to teach about climate change and forests. The accompanying website provides slide presentations, handouts, videos, and answer keys that enhance each of these activities. In addition, the website includes online training components, such as short introductions to each activity, videos explaining key concepts, and quizzes for teachers to check their understanding. These items are designed to increase educators' confidence in using these materials and can be found on each activity webpage in the **Teacher Tools** section.

Throughout the module, look for this icon which indicates that the supplemental activity materials are available on the module website (https://sfcc.plt.org).

This module is designed to help students

- understand how climate change could impact forests in the southeastern U.S.;
- understand how forests can be managed to address changing climate conditions and to reduce greenhouse gas emissions;
- enhance decision-making skills to make informed choices as consumers to mitigate climate change;
- develop systems thinking skills to understand connections between climate change, forests, and people;
- recognize that individual and community actions can help mitigate and adapt to climate change; and
- become part of future community conversations about climate change and potential solutions.

Module Overview

This module is designed for educators of students in grades 9–12, both standard and advanced placement classes. All of the activities include a section describing strategies to adapt the activities to grades 6–8 or basic high school classes. Teachers of introductory biology and environmental science classes in colleges may find these activities helpful as well. The fourteen activities build on each other to create a unit that applies what we know about climate change to forest ecosystems and forest management, making this module most appropriate for teachers of life science, biology, agriculture, and environmental science. We do not include Earth science content focused on atmospheric, hydrologic, and meteorological sciences, expect for a brief introduction in **Activity 2: Clearing the Air**. Because complex societal problems weave together science, policy, and human behavior, these activities blur the boundaries between biology, environmental science, social studies, and civics courses. As a result, teachers of government, economics, math, and language arts classes may enjoy using some of these activities too. The module website includes a subject correlations chart that may help educators choose appropriate activities for their courses (https://sfcc.plt.org/wp-content/uploads/sites/3/Subjects.pdf).

To help educators address curriculum and content standards, the website also includes correlations for the Next Generation Science Standards (https://sfcc.plt.org/wp-content/uploads/sites/3/NGSS.pdf) and the PLT Conceptual Framework (https://sfcc.plt.org/wp-content/uploads/sites/3/PLT_Concepts.pdf). Of course, each activity can be a launching pad for additional questions and extensions, but we have used the core components of each activity as the basis for these correlations. Other standards may also be achieved as teachers make adaptations to these materials.

Several learning theories and a variety of teaching strategies form the basis of these activities to help educators actively engage students in learning about a controversial, social, and scientific issue. We provide activities that help students gain scientific literacy, understand the nature of science, and apply this to climate change scenarios (Zilder et al., 2005). Our partnership with researchers enables us to design activities that use datasets and models that duplicate the ongoing work to understand climate change and forest management options. Videos on the module website (https://sfcc.plt.org) allow students to hear from these PINEMAP researchers and may spark interesting discussions about career opportunities in science and forest management. The process of resolving climate change does not have a single correct solution, and will likely require that people use skills of sys-tems thinking, critical thinking, and group process as they work together. Many of the following activities follow a problem-based learning approach with small group exer-cises designed to elicit skills in collabora-tion and higher order thinking (Barrows & Kelson, 1995). Each activity is designed to guide learners through an experience and reflection cycle where they process, generalize, and apply the key concepts (Kolb, 1984).

The fourteen activities are organized by themes into five sections. The first activity in each section introduces basic concepts; subsequent activities extend and apply those concepts. The first section introduces climate science and climate change, why people might disagree about the scientif-ic evidence, and how climate models can be used to project impacts to forests. The second section focuses on strategies that scientists and forest landowners are using to understand and adapt to an uncertain climate future. The third section introduces the strategy of carbon sequestration as one tool forest managers can use to mitigate climate change. The fourth section offers a different strategy by teaching students about life cycle assessment, which is a tool that consumers can use to select products that reduce atmospheric carbon dioxide. The final section of the module includes three activities that help summarize the themes of the module and connect ideas about carbon sequestration from Section 3 to life cycle assessment from Section 4.

Each section contains an overview to provide background information common to those activities. Based on literature and the module pilot test, we also provide a list of concepts that are likely to be student misconceptions or may generate confusion (National Research Council, 2005). This information will help educators prepare for the types of questions their students may or may not ask and address them appropriately.

Depending on the amount of available time, teachers may choose the activities in one section to supplement an important concept in their course curriculum, or they may select activities from each section to provide a reasonable overview of the module concepts. Whether additional activities are needed to introduce a concept is a function of the subject area, curriculum, and student age; therefore, individual teachers must use their discretion in making choices. In the Activity Overview, we suggest related activities in this module that are reasonable to consider using before and after each activity.

How to Use This Module

First, select a theme, a section, or an activity that you wish to use in your classroom. We recommend reading the relevant section overview before reading the activities to help set the stage and obtain background information that

Videos on the module website allow students to hear from PINEMAP researchers about ongoing studies to understand climate change and forest management.

Section	Theme	Activity
1. Climate Change and Forests	Three activities introduce the module theme by conveying how scientists currently understand observed changes in weather and climate that are impacting forest ecosystems.	**1. Stepping through Climate Science** – Students walk along a timeline of climate science and policy initiatives and then explore connections between forests and climate. **2. Clearing the Air** – After an introduction to the evidence of climate change, students explore common confusions and role-play a community discussion with the goal to reach consensus on strategies to reduce greenhouse gas emissions. **3. Atlas of Change** – Students are introduced to climate modeling to understand past changes and project future possibilities, and then use Web resources to consider how forest ecosystems might change over the next 100 years.
2. Forest Management and Adaptation	Climate changes are projected to affect surface temperature, precipitation patterns, and frequency of storm events. As scientists study how forests might change as a result, forest managers can be encouraged to alter management practices to help create resilient forests that will survive these challenges.	**4. The Changing Forests** – Students review how scientists are monitoring forest changes and exploring adaptive strategies to keep forests healthy. **5. Managing Forests for Change** – Students develop and use a systems diagram to model a forest so they can advise a forest landowner how to manage a pine plantation in light of climate projections. **6. Mapping Seed Sources** – Across the native range of loblolly pine, variations in genotype create trees that may do better under new climatic conditions. This activity helps students analyze data from three trials to determine the origin of the seeds.
3. Carbon Sequestration	Sequestering carbon in trees, soil, and wood products keeps it out of the atmosphere. Scientists are exploring if we can sequester more carbon in these carbon pools.	**7. Carbon on the Move** – Students become familiar with the carbon cycle and pathways that increase and decrease atmospheric carbon. **8. Counting Carbon** – Students measure trees near their schools and calculate the amount of carbon stored in individual trees. Students then compare the carbon sequestration potential for land-use types in their state, compare this to the estimated amount of carbon released by human activities, and discuss forests' ability to sequester atmospheric carbon.
4. Life Cycle Assessment	Consumer choices can play a role in reducing and preventing greenhouse gas emissions. These activities introduce the concept of externalities to consider the environmental problems that can occur from the production, shipping, and disposal of various products. Greenhouse gas emissions are one of the many criteria that students can use to assess products as they develop their own personal code for deciding what to purchase.	**9. The Real Cost** – Through a simulated shopping activity, students learn about the impact, or externalities, of consumer choices on the environment. **10. Adventures in Life Cycle Assessment** – Students investigate life cycle assessment data for three types of outdoor dining furniture to determine which type would generate the lowest amount of greenhouse gases. This detailed analysis of inputs and outputs is another tool for systems thinking. **11. Life Cycle Assessment Debate** – Students debate four pairs of similar products to develop their own sets of questions about product life cycles that can help guide consumer choices.
5. Solutions for Change	Three activities that help teachers summarize the concepts in this module. These can be adapted to reflect the activities that teachers selected. Students can be empowered with the knowledge and hope that all of us can help work toward healthy, sustainable forests and communities.	**12. The Carbon Puzzle** – Students use a series of facts to realize how forest plantations, wood products, and wood substitution can reduce atmospheric carbon, and then interpret a graph published by the researchers who explored this concept. **13. Future of Our Forests** – Student teams review information from the module and share their knowledge with an appropriate audience. **14. Starting a Climate Service-Learning Project** – Students select and complete an action project to mitigate climate change or help their communities adapt to projected changes.

is common to activities in that section. Consider what your students already know about this topic and consult the activity webpage to explore the additional information, videos, and systems thinking exercises.

Each activity contains the following sections:

- **Activity Overview.** Brief activity description, objectives, assessment suggestions including a student writing prompt, related subjects, skills that are practiced, materials that are needed, estimated time, connections to current scientific research, and related module activities.
- **Background.** Information about the activity topic for the teacher, with bolded and italicized words defined in the glossary.
- **Systems Thinking Connection.** Ideas for emphasizing and applying systems thinking skills.
- **Teaching This Content.** Key ideas and tips to help teachers succeed with these particular teaching strategies and content.
- **Getting Ready.** Suggestions for preparing to lead the activity.
- **Doing the Activity.** Step-by-step suggestions for how to conduct the activity, with appropriate, italicized answers to discussion questions.
- **Modifications.** Suggestions for how to modify an activity for middle school or basic science classes.
- **Enrichment.** Suggestions of ways to extend the activity.
- **Additional Resources.** Websites, readings, and reports for both teachers and students that relate to this topic.
- **References Cited.** Citations for referenced information in the background or student pages.
- **Student Pages.** Handouts and worksheets for students.
- **Teacher Comments.** Tips and suggestions from other teachers who have used this activity.

In addition, activity webpages contain the following items:

- A recorded "tour" to introduce teachers to the activity and tips for using the activity in the classroom.
- A short online quiz for teachers that covers the content in the activity and includes explanations and pointers to additional resources.
- Videos that introduce concepts or explain how researchers are exploring important questions related to this topic.
- Supplemental support for teachers on certain topics or strategies, such as graphing or creating informative posters.
- Supplemental activity materials, such as signs or cards.
- Slide presentations with teacher notes that can be adapted and used with students to explain concepts.
- Student pages in an easy-to-modify format.
- Answer keys for student pages.
- Bank of multiple-choice assessment items.

The Development Process

Several sources informed the development of this module, and additional input from content reviewers and pilot-test educators improved it. We began with a review of the existing literature and curriculum that addresses climate change education and discovered a range of informative materials. The framework of the PINEMAP project helped us develop the structure for the module, and access to the expertise of the PINEMAP researchers enabled us to generate interesting, current, and meaningful activities related to their research. The following sources were also utilized in the initial development process:

- Wise's (2010) findings from a survey of Colorado science teachers about climate change instruction
- National Center on Science Education (NCSE) Climate Change Education website (http://ncse.com/climate)

Each activity webpage contains **Teacher Tools**, which include a tour of the activity, a short online quiz, and videos to provide extra background information.

- Climate Literacy and Energy Awareness Network (CLEAN) website (http://cleanet.org)
- Global Learning and Observation to Benefit the Environment (GLOBE) website (http://www.globe.gov)

We conducted a needs assessment of science teachers in the Southeast and learned that those who responded were interested in using units of one to two weeks in length with activities that present and use data, provide opportunities for critical thinking, and explore how students can become engaged in this issue (Monroe, Oxarart, & Plate, 2013). We developed an advisory committee of teachers, PLT coordinators, and educators from the Climate Literacy Network to review the activity concepts and drafts. Their insights were extraordinarily useful. We worked with the members of the North American Association for Environmental Education (NAAEE) and EECapacity Climate Change Education Professional Learning Community for additional feedback on activity drafts. For two activities, we developed parallel versions and tested them with high school students enrolled in summer science camps at the University of Florida's Center for Precollegiate Education and Training to determine which version might be more effective. We also tested several activities with teachers at the Climate Change Symposium organized at the University of Florida in May 2013. All of these resources helped us assemble a draft module that was reviewed by 33 forestry, climate, and education experts in spring 2013.

More than 175 people helped with the module development through writing and reviewing activities, or participating in the advisory committee, expert content review, pilot test, or summative evaluation.

The revised module was used in a pilot test with more than 40 teachers in the Southeast in fall 2013. Their experiences with using the activities helped us revise the materials with clarifying explanations and examples. Their observations are sprinkled throughout the activities and on the website to provide insight that may help other teachers use these materials. We specifically asked middle school teachers to provide suggestions for younger students, and their ideas have been added to each activity in the Modifications section. From the pilot test, we learned that the activities effectively engage students in exploring and discussing issues of interest, that teachers and students can use these activities successfully, and that students improve their knowledge of climate and forests.

The contributors, advisors, reviewers, and pilot testers are listed in the acknowledgments. They have all made important and often substantial contributions to the development and improvement of this material.

Addressing Climate in the Classroom

Public opinion polls suggest that Americans hold many different beliefs about climate change. These opinions shift slightly with media coverage of extreme weather events, international meetings on climate, and new research findings. Teachers should expect that students, parents, administrators, and co-workers hold similarly diverse perspectives. However, we do not believe that all of these varying opinions should be framed in the classroom as a "scientific controversy" (McCaffrey, 2012). Although there are scientific uncertainties associated with climate change, there are not competing *scientific views* on the basic fundamentals of climate change. The controversies lie in how to apply these findings to our society, which policies to implement, and what investments to make. This module rests on the scientific conclusions that recent observations of changes in our global climate are influenced, in large part, by human activity (IPCC, 2013).

In a survey that was conducted to learn more about how to frame this module for southeastern secondary science teachers (Monroe, Oxarart, & Plate, 2013), we learned that many teachers use the topic of climate change to teach students about the nature of science. The process of making observations, forming hypotheses, collecting data, and searching for patterns and explanations is going on right now around the world. The researchers working with PINEMAP are conducting projects that answer questions about the impact of climate changes on southeastern forests: How does drought change sap flow in pine trees? How do forests respond to less frequent precipitation? What incentives will help landowners make suggested changes? Which trees have the genetic traits to thrive in future climates? This module provides opportunities for students to understand how scientists approach this complex topic (Activities 3, 4, 6) and to understand the implications of their data (Activities 5, 8, 12, 13).

In Activity 2, we focus on helping students understand why there are a variety of public opinions about climate change and how people can contribute to appropriate adaptations even if they disagree about the causes of climate change. While this activity helps students understand why people hold different ideas about climate change, it does not provide guidelines for changing those opinions. If the students (or their parents) present alternate ideas in your classroom, it may be helpful to have a careful, deliberate discussion about what lies at the root of those ideas. For some, there may be concepts that you can help clarify. For others, there may be deeply held values or attitudes that suggest that the climate change is not caused by human activities. Such a position does not negate the importance of planning for how to cope with projected changes; so you might focus your discussion on adaptation strategies, such as creating healthy, resilient forests through forest management strategies.

A focus on science, the nature of science, and the interpretation of data tends to be comfortable for science teachers and will be less likely to result in classroom conflict. It is in the implication of these findings where disagreement occurs, as well it should. Policymakers must understand the science and then balance economic tradeoffs, culture, ethics, and preferences. Activities 9 and 11 give students a chance to experience that balance in a relevant context, for example, by considering what type of shirt to buy. How much does the environmental impact matter? What else matters? What questions should they ask before purchasing something? What else do they need to know? These activities allow students to assess and compare information and to explore the values that they use to guide their consumer decision making. And this process mirrors what decision makers must do every day.

ANNIE OXARART, UNIVERSITY OF FLORIDA

This module provides opportunities for students to learn how scientists are studying topics related to forests and climate change.

Some educators hesitate to embark on the topic of climate change because it is so complex and current that it is a challenge to be able to answer students' questions. While we have provided explanations and slide presentations to cover the most obvious points, perhaps the better strategy is to ask students

This module can assist you in helping students understand the following:

- Why a variety of perspectives of climate change exist.
- How to build consensus with people who represent a variety of perspectives.
- How to explore underlying beliefs and address missing information.
- How to respect differences of opinion.
- How to find common ground of agreement.
- The scientific evidence for climate change.
- Potential impacts of climate change on ecosystems.
- The limitations and purpose of climate models and projections.
- The nature of science.
- How data are analyzed and used for inferences.
- Why policy recommendations can be sources of controversy.
- Where to find accurate answers to questions about climate change.

to find the answers to their questions! We have provided links to additional resources on the Internet in each activity. Of course, new information and research findings will be available every year so helping students find and assess the most current information is an important skill to teach too.

Climate change is a complicated environmental issue. There are deep political and religious divides across the nation and at the same time nearly unanimous agreement among climatologists. We believe this module makes an important contribution to science education in the Southeast by providing activities based on current scientific research. The most important action that educators can take is to help students build the knowledge and skills to have reasoned conversations about climate change in their communities. We are not likely to ever have all the answers, but we all need to be able to understand and discuss the risks, tradeoffs, and potential impacts of our actions.

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SECTION I

Climate Change and Forests

Forests influence and are influenced by our climate.

AS WITH ALL SYSTEMS ON EARTH, CLIMATE AND FORESTS ARE INEXTRICABLY LINKED. ***Climate***—along with other factors, such as water, soil, and geology—dictates whether and how well plants grow. This connection is easy to see by comparing the slow growth of the boreal forests of Russia and Canada to the rapid growth of the tropical forests of Latin America and Africa. However, the ways in which trees influence climate may not be so easy to see. First, trees intercept and absorb a large amount of the energy emitted by the sun, which affects air and surface temperatures. Trees also influence the amount of water vapor in the ***atmosphere***: water absorbed by tree roots evaporates through leaf surfaces in a process called ***transpiration***. This, in turn, affects climate components of humidity and ***precipitation***. Similarly, trees influence the amount of ***carbon dioxide*** in the atmosphere by removing atmospheric carbon dioxide during ***photosynthesis*** and storing carbon molecules in trunks, branches, leaves, and roots. Large amounts of carbon are also stored in the forest soil as a result of falling leaf litter and root death. All trees photosynthesize and ***respire***, moving carbon dioxide out of the air and back again. Carbon dioxide and other ***greenhouse gases*** in the Earth's atmosphere help moderate the climate, making the planet habitable by trapping heat in the atmosphere. However, additional carbon dioxide added to the atmosphere from human activities, such as land-use changes and ***fossil fuel*** combustion, is a serious concern.

Scientists have been improving their understanding of Earth's climate through numerous studies over the past 200 years. Through many scientific experiments, scientists have collected, analyzed, and compared historical climate data to arrive at the conclusion that Earth's climate is changing. Since 1880, the average surface temperature on Earth has increased by more than 0.8 degrees Celsius (° C) or 1.4 degrees Fahrenheit (° F) (NRC, 2010), and the rate of warming has doubled since 1950 (IPCC, 2007). This average increase in surface temperature, called ***global warming***, results in changes to climate averages and also influences temperature and precipitation extremes. Collectively, these changes are known as ***climate change***. In the Southeast United States, average temperatures are projected to increase over the 21st century. Precipitation patterns are also projected to change within the region, with some areas receiving more rainfall and some receiving less (Ingram, Carter, & Dow, 2012).

Through many scientific experiments, scientists have collected, analyzed, and compared historical climate data to arrive at the conclusion that Earth's climate is changing.

Words in boldface and italic are defined in the glossary.

People are approaching projected changes in the climate with a variety of adaptation and mitigation solutions.

Projected changes in climate can impact forests in several ways. For example, changes in temperature and precipitation can influence tree growth and survival. Over time, the range of some forest ***ecosystems*** may shift to new locations as ***species*** adjust to new climatic conditions. In addition, the frequency and severity of disturbances such as ***wildfires***, insects and diseases, and storms may change, which will influence ***forest health***. It is difficult to say exactly how climate may change forests because (1) the landscape of the Southeast is varied, with differing climates across coastal and mountain areas; (2) climate is a complex system with many different variables and interactions, some of which are not fully understood; and (3) over time people may change the inputs by planting different trees or changing ***greenhouse gas emissions***.

People are approaching projected changes in the climate with a variety of solutions that fall into two broad areas:

1. ***Adaptation*** is when natural or human systems adjust to a new or changing environment. While plant and animal populations have the ability to biologically adapt to new conditions over time, the rapid rates of change projected make successful adaptation more difficult. Adaptation to climate change by humans includes actions taken to avoid, benefit from, or deal with actual or expected climate change impacts. Adaptation can take place in advance (by planning before an expected impact occurs) or in response to changes that are already occurring.
2. ***Mitigation*** includes actions to reduce the human impact on the climate system. These actions may seek to decrease ***greenhouse gas emissions*** or to increase the amount of ***carbon dioxide*** being removed from the ***atmosphere***.

The activities in this section are designed to provide background and perspectives on the topic of climate change and introduce ways in which the U.S. Forest Service researchers are exploring how southeastern forests may be impacted by climate change.

ACTIVITY 1: Stepping through Climate Science introduces climate change by providing historical context of the major milestones in climate science or policy over the past two centuries. In this short introductory activity, students represent a piece of the climate timeline and walk the timeline together as a class. Students also begin to explore connections among climate, climate change, and forest ecosystems and discuss mitigation and adaptation strategies being implemented by the U.S. Forest Service to address climate change in national forests. This activity can be used to introduce any activities in the module, as it briefly covers concepts related to climate change and forests.

ACTIVITY 2: Clearing the Air provides a more detailed foundation in climate science and is particularly important if your students have not learned about climate change yet. The activity was designed to help students understand why people have different ideas and opinions about this issue, even though 97 percent of climatologists are in agreement that the climate is changing due mostly to human activities. A slide presentation helps you address the following questions: Is climate changing and why? What may happen in the Southeast? Why don't some people agree on the issue? After this introduction, students evaluate climate change information and rewrite conclusions that are supported by science. Next, students brainstorm, negotiate, and critique local solutions through a role-play.

ACTIVITY 3: Atlas of Change explores the web-based U.S. Forest Service Climate Change Tree and Bird Atlases. Students learn about projected climate changes in their state and how suitable ***habitat*** for tree and bird species is projected to change by the end of the 21st century. This activity introduces climate ***modeling*** and focuses on technology tools as students learn to navigate the atlases online and to understand the link between climate and ***biodiversity***.

Potential Areas of Confusion

There are several topics in this section that may be sources of confusion for students based on their assumptions, prior experiences, or existing knowledge. You may be able to use questions to uncover this confusion and steer students toward the clarifications provided in the table.

Assumption or Confusion	More Adequate Conception
Weather anomalies can be used to prove or disprove climate change.	***Weather*** describes the atmospheric conditions at a specific place at a specific point in time. Weather is related to, but is not the same thing, as climate. Climate is the long-term average weather conditions in a particular location or region at a particular time of the year. Climate is typically measured in long increments of time, often at least 30 years. Therefore, evidence of climate change is best assessed through long-term alterations to temperature, precipitation, and other climate factors—not through single weather events, such as a heat wave or a blizzard.
Carbon dioxide makes up a small percentage of the total gases in our atmosphere. We are not adding enough carbon dioxide to change the climate system.	There are several atmospheric gases, and many do not trap heat. Greenhouse gases, such as carbon dioxide and methane, occur naturally in small amounts, but they are very efficient at absorbing heat energy. For this reason, a small change in carbon dioxide can have large impacts on the climate system. It may be helpful to give students another example of a small percentage that has a great effect, such as how salt makes up only 3.5 percent of seawater, but that is enough to make it undrinkable.
The carbon dioxide that humans add to the atmosphere through fossil fuel combustion increases the total amount of carbon on Earth.	Carbon naturally cycles through biological, physical, and geological systems over time. The amount of carbon on Earth is stable. However, human activities are transferring carbon that is stored in fossil fuels to the atmosphere at a faster rate than would occur naturally.
The hole in the ozone layer is a large contributor to global warming.	Both the ozone hole and global warming are influenced by human activities. However, the ozone hole and global warming are different issues. The ozone hole is a depletion of the atmosphere's ozone layer, which reduces the ability of the ozone layer to protect the Earth from the sun's ultraviolet radiation. The hole is caused by the release of CFCs, or chlorofluorocarbons. Unlike reflected radiation which is absorbed as heat, ultraviolet radiation is not a large contributing factor to the average increase in global surface temperature.
Aerosol spray cans are a large contributor to global warming.	Aerosol spray cans once contained CFC's as a propellant, but not since the 1980s when we became aware of the damage to the ozone layer.
If climate changes, forests can just move to the right spot.	While migration is a reasonable possibility for some species, others will be constrained by human-caused changes in the landscape that prevent plants and animals from extending their ranges. There are no guarantees that all of the organisms that make a functional forest (e.g., fungi, insects, microorganisms) will migrate together. In addition, seed dispersal varies by species and is fairly limited for most trees. Because trees grow slowly and may not reproduce for many years, they are less likely to be able to expand their ranges rapidly enough to escape negative impacts from climatic conditions. If climate changes occur quickly and variably, existing ecosystems will be less likely to adapt and some tree species may be lost. Even when successful migration occurs, it may be many decades before the forest achieves the same age and size distribution associated with a particular forest type.
Forests are not very sensitive to changes in climate.	Trees are able to tolerate wide ranges in temperature and precipitation, making them somewhat resilient to changes in climate that are projected for the Southeast. Increases in atmospheric carbon dioxide may even help trees grow faster, at least for a few years. The biggest problems may result if climate change alters the frequency or length of severe events. For example, recent droughts in Texas have killed large numbers of trees and made others susceptible to insect attack. Slight changes in temperature may alter when plants flower, when insects hatch, and when birds migrate. Changes in precipitation affect soil moisture levels and could affect amphibians as well as plants.

(Table rows 1 through 3 adapted from CIRES, 2012; Table rows 4-5 adapted from Leiserowitz, Smith, & Marlon, 2011)

LARRY KORHNAK, UNIVERSITY OF FLORIDA

Climate and forests are interconnected systems.

Key Concepts in This Section

- Many lines of scientific evidence indicate the Earth's climate is changing and that these changes are caused by a combination of natural and human activities, particularly the combustion of fossil fuels.
- People have varying opinions and ideas about climate change, which may or may not be supported by scientific evidence.
- Communities around the world are working to minimize the effects of climate change by reducing atmospheric greenhouse gases and implementing strategies to help people and ecosystems adapt to changing climate conditions.
- Southeastern forests will probably be impacted by projected climate changes in several ways, including changes in tree growth and distribution.

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ACTIVITY

1 Stepping through Climate Science

This activity provides an overview of the connections between forests and climate. Students create a timeline of climate science over the past 200 years and gather information from a U.S. Forest Service video about climate mitigation and adaptation strategies for forests.

Subjects
Agriculture, Biology, Earth Science, Environmental Science, Language Arts, Mathematics, Social Studies

Skills
Communication, Discussing, Graphing, Inferring

Materials
Student pages, answer keys, and video (see Activity Webpage link below); 7 wire coat hangers and tape

Space Considerations
Area (inside or outside) large enough for students to form a 60-meter (or 200-foot) timeline

Time Considerations
Two to three 50-minute class periods

Related Activities
This activity helps introduce the module. It can be followed by any of the activities that help students explore climate (Activity 2) and forests (Activities 3, 4, and 5).

Research Connection
Scientists have been exploring the greenhouse effect and climate change for nearly two centuries. Many current projects are testing strategies for reducing the impact of climate change and for helping people adapt to these changes.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section1/activity1

Objectives
By the end of this activity, students will be able to
- explain three connections between forests and climate,
- describe the progression of scientific understanding of climate change, and
- define the terms adaptation and mitigation as they relate to climate change.

Assessment
- Review the Forest Service and Climate Change Video student page to see if the students understood the information from the video.
- Ask students to respond to the following writing prompt: The idea that the Earth's climate might be affected by human activities began in the late 1800s and continues to be a topic of research and investigation. What are three pieces of information that we know about climate science? What is one thing you would like to know more about?

Background

Over the past decade, many scientific studies and reports have been published on ***climate change***. This subject has been covered by the media, debated by politicians and community leaders, and discussed over dinner tables. But this doesn't mean that climate change is a "new" topic. In fact, scientists began to think about the science of ***climate*** as early as 1824, when a French scientist, Jean Baptiste Joseph Fourier, began studying ***greenhouse gases*** in our ***atmosphere*** and coined the term "***greenhouse effect***." Since that time, our understanding of the atmosphere, the greenhouse effect, the ***carbon cycle***, and climate change has continued to grow.

As scientists continue to study and understand climate change, they are also discovering how climate change might affect forest ***ecosystems***. Forests are inseparably linked to Earth's climate, as trees need water (usually in the form of rain) and sunlight to grow. Different ***species*** prefer different ***habitats*** and grow best within specific ranges of soil moisture, atmospheric moisture, and temperature. These conditions vary by region and with changes in ***topography***, so the ***structure*** and ***composition*** of forests also vary—creating diverse ecosystems in your own state and around the world. Forests can also influence climate. On a small scale, they create shade and microclimates. On a larger scale, they intercept and absorb energy emitted by the sun. Through the process of ***transpiration***, water is released from the surface of leaves, which in turn influences humidity in the atmosphere. Trees also remove ***carbon dioxide*** from the atmosphere during ***photosynthesis,*** release it into the atmosphere during ***respiration***, and store it in trunks, branches, leaves, and roots. Because of the large amounts of carbon that can be stored in forests, trees have a key role in the carbon cycle, and the reduction of forested land cover is one factor in the Earth's increasing global temperature.

Additional background information can be found in the **Section 1 Overview**.

LUDOVIC BRUCKER, NASA GODDARD SPACE FLIGHT CENTER

Ice core segments are used to study the amount of carbon dioxide present in the atmosphere at different points throughout history.

Since forests and climate are interconnected ***systems***, as the climate changes, some trees may be stressed while others may thrive. Long-term changes in average temperature and ***precipitation*** can influence ***forest health*** and survival by affecting tree growth, ***productivity***, and other disturbances such as insects and disease.

Changes in climate also affect wind and water currents, which can indirectly affect forests by influencing the frequency and severity of storms.

Resource management agencies, such as the U.S. Forest Service, are monitoring forest ecosystems to better understand what is changing and how forest managers could respond with ***adaptation*** and ***mitigation*** strategies (see activities in Section 2 and Section 3 for more details). Adaptation is an adjustment, made by natural or human systems, to environmental changes. In terms of climate change, this includes taking actions to avoid, benefit from, or deal with actual or expected impacts associated with changes in the planet's climate. Selecting species to plant or ***thinning*** a forest are two examples of forest management adaptations. Mitigation, on the other hand, includes actions that seek to decrease ***greenhouse gas emissions*** or to increase their removal from the ***atmosphere***. Communities, governments, and organizations are exploring adaptation and mitigation strategies and beginning to plan for future climate stressors. These actions can be seen in international agreements, national and local policies, and even within government agencies. The video in this activity shows students how one agency, the U.S. Forest Service, is developing adaptation and mitigation strategies as they plan and prepare for managing national forests in the face of climate change.

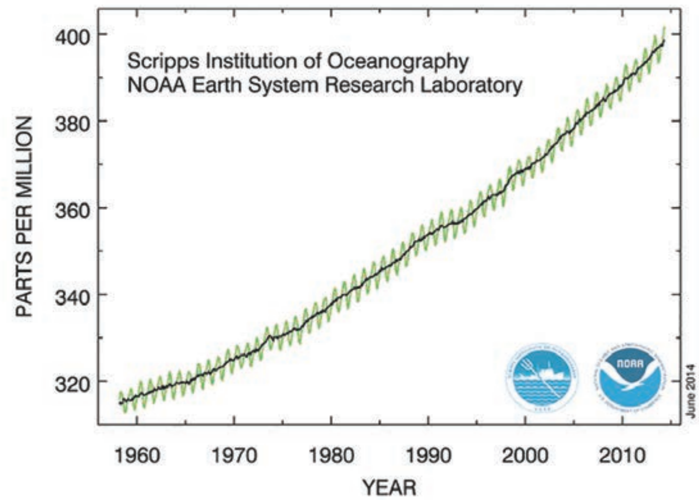
Systems Thinking Connection

SYSTEMS THINKING is a shift in focus from thinking about individual things (e.g., trees, people, products) to thinking about how those things are interconnected. It also involves a shift from focusing only on direct, linear connections—which are often easiest to see—to including multiple, indirect connections. To help students make these shifts, we suggest beginning this activity with a slight deviation by completing the **Learning about a Tree** systems exercise on the Activity 1 webpage. This supplementary discussion will help students understand how systems thinking can change the way that we think about a tree. An additional systems exercise, **Dynamic Systems Dance**, is described in the Systems Enrichment Exercise section.

ANNIE OXARART, UNIVERSITY OF FLORIDA

You can make timeline signs by folding the Interval Sign over a wire coat hanger and straightening the hanger hook to stick into the ground.

Atmospheric CO_2 at Mauna Loa Observatory



Data and Figure by Dr. Pieter Tans, NOAA/ESRL Keeling, Scripps Institution of Oceanography (scrippsco2.ucsd.edu)

This figure, known as the Keeling Curve, shows the atmospheric carbon dioxide concentrations measured at Mauna Loa, Hawaii from 1958 to 2014. The green curve represents seasonal fluctuations in carbon dioxide, and the black curve represents seasonally corrected data.

Teaching This Content

This activity provides an introduction for the module—no matter which activities you choose to use next. If you are introducing the topic of climate change in your classroom, we suggest starting with this activity. If you are unsure of how your students will react to the topic of climate change, making a timeline is an easy, fact-based introduction to the subject. None of the items on the timeline are controversial; they are part of history. Still, students may find different ways to interpret these facts, which Activity 2 explores in greater detail.

Getting Ready

The Activity 1 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section1/activity1).

Select an area that enables you to make a timeline that is approximately 60 meters (200 feet) long. It can be in the schoolyard, a field, a hallway, or the interior of the school gym. The timeline can be linear or can wrap around the perimeter of a room or large circle.

Set up your timeline by posting interval signs to designate the amount of carbon dioxide measured in the atmosphere at key years. To create these signs, visit the Activity 1 webpage to download and print the Timeline Interval Signs. If you make your timeline outdoors, print the carbon dioxide labels on a piece of paper and fold them over the long part of a wire coat hanger (as shown in the photo). Straighten the hook of the hanger to form the stake. If you conduct the timeline activity inside, tape the signs on the wall. Space the carbon dioxide signs along your timeline, with each year representing one step (numbers of steps are listed on the Master Timeline).

Print and cut the Timeline Cards student page. They can be laminated for multiple uses. There are 25 event cards in the timeline. If you have more than 25 students, check the Activity 1 webpage for extra cards or have your students look up other world events within the designated years. Use the Master Timeline to help you provide verbal prompts and guidance to the students.

U.S. FOREST SERVICE

This activity begins with a discussion about climate change. You might wish to take this conversation outdoors!

Make copies of the Climate Science Timeline student page and the Forest Service and Climate Change Video student page (one per student).

Be sure you can access the U.S. Forest Service video on the Activity 1 webpage.

Doing the Activity

Part A: Climate Change Timeline

1. Begin this activity with a discussion, which can take place inside or outside for inspiration. If outside, pick a tree to sit or stand near. Tell students that they are beginning a unit to explore climate, climate change, and forests. Then lead a class discussion with these questions.

- What do you think of when you hear the words climate change?
  Responses will vary. If you believe this could be a contentious issue, remind students of ground rules such as students have a right to their opinions and that this is a safe forum to speak their minds.
- How long do you think scientists have been talking about the greenhouse effect and climate change?
  Responses will vary. Start the timeline activity so they can learn the answer!

2. Give each student a card for the timeline. Also give each student a copy of the Climate Science Timeline student page. Walk them to the area where you have arranged the atmospheric carbon dioxide signs. Explain to students that they will be creating a climate science timeline by reading their cards one by one in order. Their cards represent two categories of events (1) scientific inventions, achievements, or discoveries and (2) domestic or international environmental policies. If your students are not familiar with the term *parts per million* (ppm), introduce this unit of scientific measurement, which is used to describe carbon dioxide concentrations in our atmosphere.

3. From the starting point of the first carbon dioxide sign at 1823, instruct the entire class to take one step to 1824 and ask for the student with the card labeled 1824 to read it aloud. Moving one step for every year, your next stop will be 35 steps to 1859. As each card in the timeline is read, ask the class if this was a scientific finding or a contribution related to policy and to mark an X on the appropriate timeline on their student pages. Help students plot the carbon dioxide levels on the graph on the Climate Science Timeline student page as they come across interval signs on the timeline. The Master Timeline tells you how many steps to take, identifies the card as science or policy, and provides reinforcing prompts for you to help students make sense of the events.

4. When the timeline is complete, provide a few minutes for students to finish the Climate Science Timeline student page. You can then use the questions on the student page to guide a discussion about the timeline.

- What event or piece of information surprised you the most?
  Responses will vary.
- Are there any events or pieces of information that were confusing to you?
  Responses will vary.
- What is happening to the amount of atmospheric carbon dioxide?
  The annual average measurement of atmospheric carbon dioxide has been increasing; levels have increased from 290 ppm in 1823 to 396 ppm in 2013, with much of the increase occurring in the later period of the timeline. You could ask students to calculate the percent change so they can understand that from 1823 to 1963, levels rose by 9.7 percent, and that from 1963 to 2013, levels rose by 24.5 percent. The example below outlines the steps in this calculation.

To calculate percent change from carbon dioxide in 1963 at 318 ppm to carbon dioxide in 2013 at 396 ppm, complete the following steps:
1) Calculate the change by subtracting the old value from the new value 396 – 318 = 78
2) Divide the change by the old value 78 ÷ 318 = 0.245
3) Convert to a percentage by multiplying by 100. The percent change is 24.5%.

- What trends do you notice about the dates of the science and policy events? Provide an explanation for why this might have happened.
  The science events occur throughout the timeline, while most of the policy events occur toward the end of the timeline. The first policy card did not appear on the timeline until 1988, and international policy preceded U.S. policy. Policy follows science.

Part B: Climate and Forests Video

1. Back in the classroom, ask students to describe some connections between trees and climate. How do they think changes in climate can affect trees? How do trees affect climate?
Trees create a microclimate with shade and moisture; trees are affected by climate conditions such as temperature, moisture, and storms. Climate can impact trees in many ways such as which trees live where, growing cycles, and resilience. The growth rate of trees could be affected if there is less water available because of droughts and warmer temperatures for longer periods of time.

2. Distribute the Forest Service and Climate Change Video student page and ask students to review the questions prior to watching the video to help them recognize the answers when they hear them.

3. Then show the video from the Activity 1 webpage and ask the students to complete the student page. The video is approximately 13 minutes long; suggested stopping points are at 8:17 and 10:35 for discussion. Alternatively, you may decide to have students watch the video for homework.

4. After the video, allow time for students to answer these discussion questions in small groups or individually and then review as a class. Use the following question to review this important concept:

- The video states, "If trees are destroyed, they release carbon into the atmosphere and thus become a source of greenhouse gas emissions." This is a problem in the short term. What could happen that would reduce this problem in the long term?
  The forest could be replanted and young trees could store the carbon that the harvested forest released. Or if the trunks of the harvested trees were made into wooden furniture or homes, those products could continue storing the carbon for a long period after the harvest.

TEACHERS SAY ...

The timeline allows for movement and has students working cooperatively. It also has the potential for further research of topics within the timeline.

—AP Environmental Science Teacher, Florida

My students liked the video. It was a good way to introduce my students to forestry and climate change.

—Environmental Science Teacher, Virginia

MORGAN CHEEK, NORTH CAROLINA STATE UNIVERSITY

5. Summarize this activity by asking students to review three things they learned about the history of climate. What concerns them about climate and forests? You might emphasize that scientists have been thinking about the impacts of increasing atmospheric carbon on the global climate for more than 200 years. Let students know that adaptation and mitigation strategies are currently being implemented to reduce the impact of climate change on forests. At this point, you can introduce the next activity from this module that you will be using with your students to explore these ideas further.

The supplemental exercise, **Dynamic Systems Dance**, can help you explain systems and their behavior to students.

- Systems Reflection: Name one of the systems discussed in the timeline or video and a variable that impacts that system.
  The ocean is a system and additional carbon dioxide affects ocean health; forests are a system and variations in rainfall may affect tree health or groundwater supplies; the atmosphere is a system and additional carbon dioxide affects global temperature.

Modifications

Depending on the needs and abilities of your students, you may want to edit the timeline cards to simplify the information provided or to select only certain cards from the list. You can download the file from the Activity 1 webpage.

Review unfamiliar terms prior to doing the timeline with students.

Enrichment

Students can add other events to the timeline to provide a frame of reference for climate events. Additional events could include domestic or international legislation, historical world events such as wars, other scientific achievements and discoveries, or environmental events such as the first Earth Day. Students can write a biography or vignette

Systems Enrichment Exercise

IMPROVED SYSTEMS THINKING SKILLS should help students better understand climate change, the role of forests in affecting climate change, and how people can mitigate and adapt to climate changes. In several activities, supplemental systems exercises are available on the activity webpages to enable teachers to focus attention on various aspects of systems and draw attention to how students can think about them. The **Dynamic Systems Dance** is a short exercise that can be conducted outdoors and can help you explain systems and their behavior to students. It can give you a foundation to refer to as you help students understand how complex systems respond to changes. This exercise can be found on the Activity 1 webpage and is based on a similar process described in the "Triangles" activity in The Systems Thinking Playbook by Linda Booth Sweeney and Dennis Meadows, 2010.

about one of the climate scientists featured in the timeline.

Additional Resources

Adapting to Climate Change: A Short Course for Land Managers
U.S. Forest Service, Climate Change Resource Center
http://www.fs.fed.us/ccrc/hjar/index_st.html
A series of videos and graphics illustrating the key concepts of climate change, possible impacts on U.S. forests and grasslands, and various strategies for adapting terrestrial systems to climate change.

Climate Change Resource Center
U.S. Forest Service
http://www.fs.fed.us/ccrc/
The Climate Change Resource Center provides information about basic climate sciences and compiles knowledge resources and support for adaptation and mitigation strategies. The site offers educational information, including basic science modules that explain climate and climate impacts, decision-support models, maps, simulations, case studies, toolkits, and videos.

Climate Connections Special Series
National Public Radio
http://www.npr.org/series/9657621/climate-connections
This NPR special features videos, articles, and interactive maps to look at the causes and signs of climate change, along with stories about solutions and adaptation.

The Climate Reality Project, Videos
The Climate Reality Project
http://climaterealityproject.org/video/
This website has several videos about climate change, carbon emissions, and solutions. Be sure to check out "Climate 101 with Bill Nye" to get a brief explanation of climate change and its potential effects on our planet.

Global Climate Change
NASA
http://climate.nasa.gov
This website provides information on the evidence, causes, effects, and uncertainties of climate change. There is also recent data on Earth's "vital signs" including global temperature, carbon dioxide levels, and the rate of sea level rise.

Natural Inquirer Science Education Journal
U.S. Forest Service
http://www.naturalinquirer.org/Natural-Inquirer-Climate-Change-Articles-v-80.html
The Natural Inquirer is a middle-school science education journal that is based on U.S. Forest Service research. Many issues have articles related to climate change, and all resources are available for download or you can order free copies.

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TEACHERS SAY ...

When I taught this lesson, the kids wanted more. They enjoy these engaging activities.

—Earth Science Teacher, Florida

The discussions on climate science we had in class were powerful. Lots of debating on the position of science vs. government vs. stakeholders. I think this activity got them thinking and evaluating current climate science research and legislation.

—IB Biology II Teacher, Florida

Master Timeline (1 of 4)

Most of the events listed in the timeline below came from *The Discovery of Global Warming* by S. Weart (2010) and *The History of Climate Science* by J. Mason (2013). Events from additional references are cited in text. The carbon dioxide levels came from NOAA's Global Greenhouse Gas Reference Network (Tans & Keeling, 2014). Full citations can be found in the References Cited section of this activity.

Year	Event	Science or Policy	Reinforcing Prompt	Steps
1823	Carbon dioxide in the atmosphere was about 290 parts per million.	Interval Sign	While tools were not available at the time to measure atmospheric carbon dioxide levels, in the 1980s scientists learned how to measure air bubbles trapped in ice cores to determine atmospheric carbon dioxide levels from the past.	Walk 1 step
1824	Jean Baptiste Joseph Fourier (FOO-ree-ey), a French scientist, described Earth's atmosphere as an insulating blanket for the planet. He was the first to use the phrase the "greenhouse effect" to illustrate how the greenhouse gases keep the Earth a comfortable temperature despite our great distance from the sun.	Science		Walk 35 steps
1859	John Tyndall (TIN-dull), an Irish physicist, discovered that carbon dioxide is very good at trapping heat in the atmosphere. He worked with a variety of gases found in the atmosphere and found that carbon dioxide can block heat radiation.	Science		Walk 37 steps
1896	Svante Arrhenius (Suh-VAN-tay Are-REY-nee-oos), a Swedish scientist, was the first to say that increases in carbon dioxide in our atmosphere due to burning coal would cause a global warming effect.	Science	Coal replaced wood as the predominant energy source in the United States.	Walk 21 steps
1917	Alexander Graham Bell, a Scottish scientist and inventor of the telephone, wrote, "The unchecked burning of fossil fuels would have a sort of greenhouse effect" and "The net result is the greenhouse becomes a sort of hot-house."	Science	While Bell was most famous for the invention of the telephone, he worked in many fields of science. The 1917 paper was about natural resource depletion and demonstrated that many scientists were concerned about the impacts of green-house gases.	Walk 14 steps
1931	E.O. Hulburt, an American scientist, continued the work of Arrhenius (Are-REY-nee-oos), to include atmospheric water vapor and found that increases in carbon dioxide levels would increase global average temperatures by as much as approximately 4 degrees Celsius.	Science	This is equivalent to 7.2 degrees Fahrenheit.	Walk 7 steps

Master Timeline (2 of 4)

Year	Event	Science or Policy	Reinforcing Prompt	Steps
1938	Guy Callendar, an English engineer, looked at historical temperature records and carbon dioxide levels from around the world and concluded that levels had increased almost 10 percent since the 19th century and temperatures were warming globally.	Science		Walk 18 steps
1956	Gilbert Plass, an American physicist, published *The Carbon Dioxide Theory of Climate Change,* and said that more carbon dioxide in the atmosphere would increase global warming.	Science		Walk 1 step
1957	Roger Revelle (Ra-VELL), a scientist in California, said that there is a limit to how much carbon dioxide the ocean could absorb from the atmosphere and remain healthy.	Science	Previously, scientists thought the ocean could absorb unlimited amounts of carbon dioxide.	Walk 1 step
1958	Charles David Keeling (KEY-ling), a scientist from California, used new technology to measure levels of carbon dioxide in the atmosphere. Keeling measured atmospheric carbon dioxide levels to be 315 parts per million in 1958.	Science	The measurement stations that Keeling established in Antarctica and Mauna Loa, Hawaii, still function. They have allowed scientists to keep track of carbon dioxide levels and establish an increasing trend.	Walk 5 steps
1963	The annual average of carbon dioxide in the atmosphere was measured at 318 parts per million.	Interval Sign	Remember, the timeline started at 290 parts per million in 1823.	Walk 4 steps
1967	Syukuro Manabe (Shoo-KOO-roo Mah-NAH-bay), a meteorologist from Tokyo University, created the first computer model simulation of Earth's climate. This complex model included many variables and reaffirmed that the climate was changing, not only at Earth's surface but also throughout the atmosphere.	Science		Walk 6 steps
1973	The annual average of carbon dioxide in the atmosphere was measured at 330 parts per million.	Interval Sign		Walk 8 steps
1981	Climatologists Tom Wigley and Phil Jones wrote that "the effects of carbon dioxide may not be detectable until around the turn of the century. By this time, atmospheric carbon dioxide concentration will probably have become sufficiently high that a climatic change significantly larger than any which has occurred in the past century could be unavoidable."	Science		Walk 2 steps
1983	The annual average of carbon dioxide in the atmosphere was measured at 343 parts per million.	Interval Sign		Walk 2 steps
1985	A group of Russian scientists at the Vostok (VAH-stock) Station in Antarctica drilled an ice core about 2 kilometers (more than 1,980 meters or 6,500 feet!) deep. This ice core held approximately 150,000 years of climate history trapped in air bubbles.	Science	This is how we knew the carbon dioxide levels in 1823 when we started the timeline.	Walk 3 steps

Master Timeline (3 of 4)

Year	Event	Science or Policy	Reinforcing Prompt	Steps
1988	The Intergovernmental Panel on Climate Change (IPCC) was started. This international organization includes scientists and government officials from around the world who help synthesize climate science and make recommendations about how greenhouse gas emissions and climate change will impact the Earth and its inhabitants.	Policy		Walk 4 steps
1992	A significant number of the world's nations recognized that climate change needed to be addressed globally and formed the United Nations Framework Convention on Climate Change. Nearly every country, including the United States, signed the agreement.	Policy		Walk 1 step
1993	The annual average of carbon dioxide in the atmosphere was measured at 357 parts per million.	Interval Sign		No steps
1993	Ice cores from Greenland showed that in the past, drastic climate changes occurred in a span of only 10 years. This greatly changed impressions that a changing climate only happens on a slow, gradual basis.	Science		Walk 4 steps
1997	Negotiations at the United Nations' Conference on Climate Change in Kyoto, Japan, resulted in the Kyoto Protocol, an international agreement to reduce greenhouse gases.	Policy	The U.S. signed the Kyoto Protocol on November 12, 1998. However, the Protocol met opposition in the U.S. Congress and was never ratified.	Walk 6 steps
2003	The annual average of carbon dioxide in the atmosphere was measured at 376 parts per million.	Interval Sign		No steps
2003	Scientists reported that the increase in atmospheric carbon dioxide resulted in increased absorption of carbon dioxide in the oceans, causing a change in the pH of the oceans. The change in pH, which continues today, is larger than anything in the geological record for the last 300 million years (Caldeira & Wickett, 2003).	Science	Recall Roger Revelle from 1957, who thought the oceans can only absorb so much carbon and be healthy. This was proof that he was correct!	Walk 2 steps
2005	The European Union Emissions Trading System was launched to reduce greenhouse gas emissions through a "cap and trade" program.	Policy	A cap and trade program creates incentives for companies to reduce emissions and forces companies who pollute to pay for the privilege.	Walk 2 steps

Master Timeline (4 of 4)

Year	Event	Science or Policy	Reinforcing Prompt	Steps
2007	Scientists reported that the melting of Arctic sea ice has been faster than models originally predicted. They showed the rate of melting was accelerating (Stroeve et al., 2007).	Science		No steps
2007	The United Nations Framework Convention on Climate Change made important decisions on a climate change mitigation solution that seeks to reduce emissions from deforestation in developing countries. That initiative is called REDD+ (Red Plus).	Policy	This policy agreement is helping countries that still have forests to keep them.	Walk 1 step
2008	The U.S. Forest Service published a report called a "Strategic Framework for Responding to Climate Change," which outlined strategies that support adaptation to climate change in our national forests.	Policy		Walk 1 step
2009	The U.S. Interagency Climate Change Adaptation Task Force was created to develop recommendations for the U.S. president to prepare for and adapt to the effects of climate change at the national level.	Policy		Walk 4 steps
2013	The annual average of carbon dioxide in the atmosphere was measured at 396 parts per million.	Interval Sign	In May 2014, the daily average for atmospheric carbon dioxide exceeded 400 parts per million for the first time in recorded history. The level of carbon dioxide in the atmosphere varies by season, peaking in May just before many trees in the northern hemisphere get new leaves and begin to photosynthesize. The average annual level is not yet at 400 parts per million.	No steps
2013	Scientists measured the mean global temperature at 14.6 degrees Celsius, the warmest it has been in thousands of years.	Science	This average global temperature is equivalent to approximately 58 degrees Fahrenheit.	No steps
2013	The United States president, Barack Obama, signed an executive order that created the Council on Climate Preparedness and Resilience. The council works to help federal programs prepare for climate-related changes and provide information for the public.	Policy	This new Council replaced the Interagency Climate Change Adaptation Task Force.	Walk 1 step
2014	While much of the eastern United States experienced a colder than normal winter, it was warmer than normal in the Arctic (National Snow and Ice Data Center, 2014).	Science	It was so warm in the Arctic that the sea ice did not extend as it typically does. The winter of 2014 was the fourth lowest extent of Arctic sea ice ever recorded by satellites during February.	Done!

Timeline Cards (1 of 3)

1824	Jean Baptiste Joseph Fourier (FOO-ree-ey), a French scientist, described Earth's atmosphere as an insulating blanket for the planet. He was the first to use the phrase the "greenhouse effect" to illustrate how the greenhouse gases keep the Earth a comfortable temperature despite our great distance from the sun.
1859	John Tyndall (TIN-dull), an Irish physicist, discovered that carbon dioxide is very good at trapping heat in the atmosphere. He worked with a variety of gases found in the atmosphere and found that carbon dioxide can block heat radiation.
1896	Svante Arrhenius (Suh-VAN-tay Are-REY-nee-oos), a Swedish scientist, was the first to say that increases in carbon dioxide in our atmosphere due to burning coal would cause a global warming effect.
1917	Alexander Graham Bell, a Scottish scientist and inventor of the telephone, wrote, "The unchecked burning of fossil fuels would have a sort of greenhouse effect" and "The net result is the greenhouse becomes a sort of hot-house."
1931	E.O. Hulburt, an American scientist, continued the work of Arrhenius (Are-REY-nee-oos), to include atmospheric water vapor and found that increases in carbon dioxide levels would increase global average temperatures by as much as approximately 4 degrees Celsius.
1938	Guy Callendar, an English engineer, looked at historical temperature records and carbon dioxide levels from around the world and concluded that levels had increased almost 10 percent since the 19th century and temperatures were warming globally.
1956	Gilbert Plass, an American physicist, published *The Carbon Dioxide Theory of Climate Change,* and said that more carbon dioxide in the atmosphere would increase global warming.
1957	Roger Revelle (Ra-VELL), a scientist in California, said that there is a limit to how much carbon dioxide the ocean could absorb from the atmosphere and remain healthy.
1958	Charles David Keeling (KEY-ling), a scientist from California, used new technology to measure levels of carbon dioxide in the atmosphere. Keeling measured atmospheric carbon dioxide levels to be 315 parts per million in 1958.

Timeline Cards (2 of 3)

1967	Syukuro Manabe (Shoo-KOO-roo Mah-NAH-bay), a meteorologist from Tokyo University, created the first computer model simulation of Earth's climate. This complex model included many variables and reaffirmed that the climate was changing, not only at Earth's surface but also throughout the atmosphere.
1981	Climatologists Tom Wigley and Phil Jones wrote that "the effects of carbon dioxide may not be detectable until around the turn of the century. By this time, atmospheric carbon dioxide concentration will probably have become sufficiently high that a climatic change significantly larger than any which has occurred in the past century could be unavoidable."
1985	A group of Russian scientists at the Vostok (VAH-stock) Station in Antarctica drilled an ice core about 2 kilometers (more than 1,980 meters or 6,500 feet!) deep. This ice core held approximately 150,000 years of climate history trapped in air bubbles.
1988	The Intergovernmental Panel on Climate Change (IPCC) was started. This international organization includes scientists and government officials from around the world who help synthesize climate science and make recommendations about how greenhouse gas emissions and climate change will impact the Earth and its inhabitants.
1992	A significant number of the world's nations recognized that climate change needed to be addressed globally and formed the United Nations Framework Convention on Climate Change. Nearly every country, including the United States, signed the agreement.
1993	Ice cores from Greenland showed that in the past, drastic climate changes occurred in a span of only 10 years. This greatly changed impressions that a changing climate only happens on a slow, gradual basis.
1997	Negotiations at the United Nations' Conference on Climate Change in Kyoto, Japan, resulted in the Kyoto Protocol, an international agreement to reduce greenhouse gases.
2003	Scientists reported that the increase in atmospheric carbon dioxide resulted in increased absorption of carbon dioxide in the oceans, causing a change in the pH of the oceans. The change in pH, which continues today, is larger than anything in the geological record for the last 300 million years.

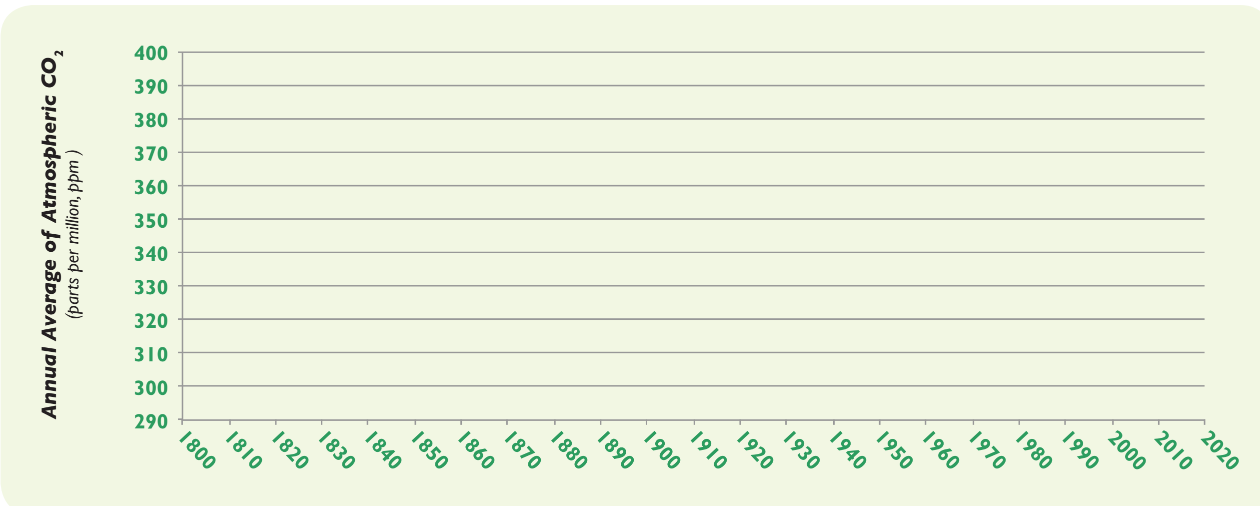
Timeline Cards (3 of 3)

2005	The European Union Emissions Trading System was launched to reduce greenhouse gas emissions through a "cap and trade" program.
2007	Scientists reported that the melting of Arctic sea ice has been faster than models originally predicted. They showed the rate of melting was accelerating.
2007	The United Nations Framework Convention on Climate Change made important decisions on a climate change mitigation solution that seeks to reduce emissions from deforestation in developing countries. That initiative is called REDD+ (Red Plus).
2008	The U.S. Forest Service published a report called a "Strategic Framework for Responding to Climate Change," which outlined strategies that support adaptation to climate change in our national forests.
2009	The U.S. Interagency Climate Change Adaptation Task Force was created to develop recommendations for the U.S. president to prepare for and adapt to the effects of climate change at the national level.
2013	Scientists measured the mean global temperature at 14.6 degrees Celsius, the warmest it has been in thousands of years.
2013	The United States president, Barack Obama, signed an executive order that created the Council on Climate Preparedness and Resilience. The council works to help federal programs prepare for climate-related changes and provide information for the public.
2014	While much of the eastern United States experienced a colder than normal winter, it was warmer than normal in the Arctic.

Climate Science Timeline (1 of 2)

NAME DATE

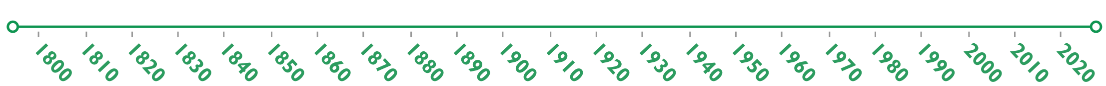
1. On the graph below, plot the measurements of atmospheric carbon dioxide (CO_2) as you step through the timeline of climate science. Once you make it through the entire timeline, connect the dots with straight lines to see how the amount of carbon dioxide in the atmosphere has changed over the past 200 years.



2. Mark the climate history events on the two timelines below. The events are categorized as either science or policy. As you listen to the dates of these events, add an "X" at the appropriate place on the correct timeline to indicate when that event took place.

Science Events:

Policy Events:



Climate Science Timeline (2 of 2)

3. Provide a one to two sentence response for the following questions.
   a. What event or piece of information surprised you the most?

   b. Are there any events or pieces of information that were confusing to you?

   c. What is happening to the amount of CO_2 in the atmosphere?

   d. What trends do you notice about the dates of the science and policy events? Provide an explanation for why this might have happened.

Forest Service and Climate Change Video (1 of 2)

____
NAME DATE

Read over the following questions. Then watch the 13-minute video to learn more about what the U.S. Forest Service is doing to help our forests as we deal with a changing climate. Answer the questions as you watch the video.

Video Questions

1. What is the environmentally friendly machine that helps to trap carbon dioxide (CO_2)? ________________

2. What is the process by which trees remove CO_2 from the atmosphere?

3. Forests cover almost ____________________ of the world's total land area and account for ________% of the annual interchange of carbon between the atmosphere and the land.

4. Name the three main roles of the U.S. Forest Service with regard to climate change:

   1) ____

   2) ____

   3) ____

Video Break Discussion

5. What is mitigation? Describe one example of this strategy used by the U.S. Forest Service and explain how it mitigates against climate change.

Video Break Discussion

6. What is adaptation? Describe one example of this strategy and explain why it is an adaptation to future climate change.

7. Finish the quote: "It's not only about changing light bulbs, it's about changing

   ______________________________ and ______________________________."

Forest Service and Climate Change Video (2 of 2)

After Video Discussion Questions

1. What is the difference between adaptation and mitigation?

2. What is one practice that the U.S. Forest Service does to operate sustainably that your school could also do?

3. The video mentions both cutting down trees for wood products and planting trees to create new forests as mitigation strategies. How can both actions reduce the amount of CO_2 in the atmosphere?

ACTIVITY 2 Clearing the Air

Students learn about the scientific evidence supporting climate change, use this information to evaluate and improve conclusions some people might draw about climate change, and participate in a role-play to negotiate solutions. Through this activity, students explore the nature of science and better understand why there are various perspectives about climate change.

Subjects
Agriculture, Biology, Earth Science, Environmental Science, Language Arts, Social Studies

Materials
Student pages, answer keys, and presentations (see Activity Webpage link below)

Skills
Analyzing, Communication, Concluding, Decision Making, Discussing, Inferring

Time Considerations
Two to four 50-minute class periods and homework

Related Activities
This activity helps introduce climate change. It can follow an introduction to forests and climate (Activity 1) and be followed by any of the activities that help students explore the relationship between climate and forests (Activities 3, 4, or 5) or between climate and product life cycles (Activity 10).

Research Connection
Research on climate change and on its impacts to ecosystems is advancing very quickly. Additional research explores how people perceive climate change. This activity summarizes what we currently know about both.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section1/activity2

Objectives

By the end of this activity, students will be able to

- assess the scientific accuracy of conclusions or statements about climate change,
- explain two reasons for diverse perspectives on climate change, and
- explain the value of solutions that incorporate diverse perspectives.

Assessment

- Ask students to write an essay based on this prompt: Please summarize scientific evidence about global climate change. Describe one aspect of the issue that is misinterpreted by the public and explain why this might occur.
- Have students analyze an editorial article on climate change. They should identify the article's claim, the strength and source of the supporting scientific evidence, and assumptions made by the author.

Background

A variety of ideas, opinions, and beliefs surround the topic of ***climate change***. While some of these beliefs are supported by scientific evidence, others are not. Beliefs are ideas that we hold to be true and can be based on many things, such as past experiences, observations, faith, or the beliefs of others. Scientific conclusions are beliefs that are based on scientific evidence. The scientific process involves testing hypotheses, collecting data through standardized measurements and observations, and stating assumptions that are used to link the interpretation of data to conclusions. Understanding scientific evidence and the reasons that people might hold ideas that conflict with the scientific consensus are key aspects of working together to move toward solutions for mitigating and adapting to climate change.

Additional background information can be found in the **Section 1 Overview**.

The **Explaining the Evidence** presentation will help you provide students with a brief introduction to climate change, scientific evidence supporting human-induced climate change, and projected regional impacts. The background text here can be used along with the presentation notes found on the Activity 2 webpage.

Is Climate Changing?

Climate is the long-term average weather conditions in a particular location or region at a particular time of the year. For example, it is generally hotter in the summer than in the spring, and it is typically cooler in the upper latitudes than in the equatorial regions. ***Weather***, as opposed to climate, describes the atmospheric conditions at a specific place at a specific point in time. Weather is what is happening outside right now.

One example of climate-related variation is the ***El Niño-Southern Oscillation (ENSO)*** cycles in the Pacific Ocean

DUNCAN WILSON, OKLAHOMA STATE UNIVERSITY

Weather station towers, like the one pictured here, collect data on rainfall, temperature, and other measures.

that create El Niño and La Niña. They have important seasonal influences on regional climates on land, especially in the Southeast—leading to warmer, cooler, wetter, or drier years. Climate also fluctuates over longer periods of time. Climate is measured in increments of at least 30 years, but when considering historical climate changes, we often look at much longer timeframes, in the range of hundreds to thousands of years. Evidence of climate change can be seen in long-term alterations of temperature, ***precipitation*** patterns, sea ice extent, sea level, and the frequency of extreme weather events. Data about these variables are collected through weather instruments and records, tree rings, ice cores, satellite images, sedimentary layers, and other observations and technical measurements.

Temperature Trends

Collectively, data from meteorological weather stations, at airports, on mountains, on ships in the ocean, and by satellites, indicate that over the past 100 years the average surface temperature on Earth has increased by more than 0.8 degrees Celsius (° C), which is equivalent to 1.4 degrees Fahrenheit (° F) (NRC, 2012). Looking at global temperature from 1880 to today, studies show that most of the increase in average temperature has occurred since the 1970s (NASA GISS, 2012). In the Southeast, as with the global averages, the annual average temperature has increased the most since 1970, by approximately 1.1° C (2° F) (USGCRP, 2009). This average increase in global surface temperature is known as ***global warming*** and can create other changes in climatic conditions, such as changes in rainfall.

Precipitation Trends

While the total precipitation in the U.S. has increased by about 5 percent in the past 50 years, this increase has not been consistently experienced by all locations in the country (NRC, 2012). Precipitation frequencies and distributions vary widely with short distances, so it is more helpful to look at regional changes in precipitation rather than global changes. In the Southeast, observed precipitation changes from 1901 to 2007 show that average fall precipitation increased by 30 percent since the early 1900s, and that summer and winter precipitation decreased by almost 10 percent in the eastern part of the region (USGCRP, 2009). Seasonal changes such as these can be masked in annual averages, but they can be critically important when precipitation changes occur during the growing season.

Other Natural Trends

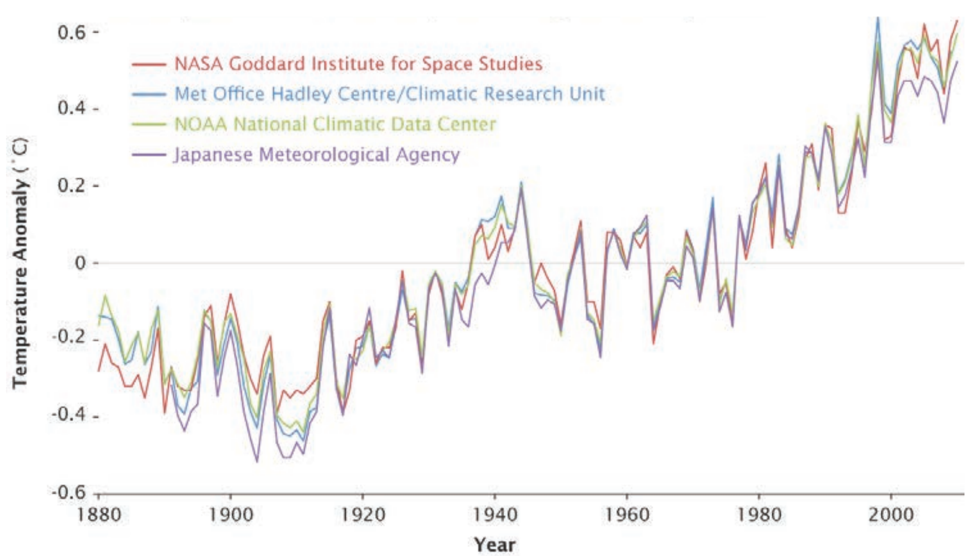
In addition to temperature and precipitation changes, climate research shows long-term changes to the extent of snow and ice cover. For example, measurements taken by the National Snow and Ice Data Center (2013) indicate that the monthly December Arctic sea ice extent from 1979 to 2012 shows a decline of 3.5 percent per decade. In addition, the average Arctic sea ice extent for December 2012 was the second lowest month in the satellite records ranging from 1979 to 2012. It is important to compare the same months across years, as comparing the ice extent in December to the ice extent in July would represent a change in season rather than a change in climate.

Increases in global surface temperature are reflected in the Earth's oceans. Like any body of liquid, a warmer ocean expands as the molecules move at greater speeds, and larger oceans encroach on shorelines, affecting ***ecosystems*** and built structures. This expansion of warm water has contributed to global ***sea level rise***, which is estimated to be about 20 centimeters (or 8 inches) higher than it was in 1870 (NRC, 2012). Sea levels are also affected to some degree by melting glaciers and polar land ice. Icebergs and sea ice already displace water, so these do not change sea level when they melt. Sea levels, which vary depending on location, are measured with tide gauges and satellite images. Warmer water also affects ocean currents, storm events, and weather patterns.

Finally, climate change can also be seen through long-term alterations to the frequency and intensity of weather events, such as periods of extreme heat or cold, droughts, floods, winter storms, thunderstorms, tornadoes, and hurricanes. Similar to precipitation, trends in extreme weather events are best identified regionally and must be considered with regard to the range of weather patterns that typically affect a specific area. In the southeastern region, the trends in weather events vary. The frequency of flood events has been increasing since the late 1800s, and particularly within the last two decades. This may be due to increases in impermeable surfaces in cities across the region as well as to climate change. At the same time, decadal frequencies of hurricane landfalls in the region have slightly decreased in the past 100 years. The frequencies of regional extreme maximum temperatures and extreme minimum temperatures have been decreasing across much of the region since the early 20th century. However, the majority of the southeastern region has been experiencing more minimum temperatures above 24° C, which is equivalent to 75° F (Ingram, Carter, & Dow, 2012).

Global Surface Temperatures

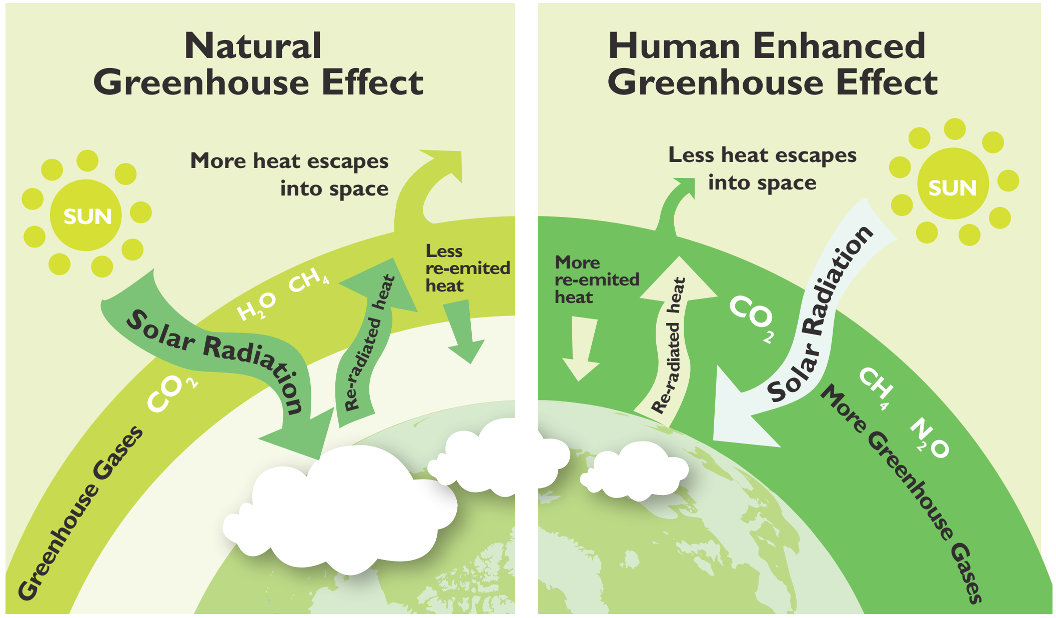
Four independent records show nearly identical long-term warming trends.



NASA EARTH OBSERVATORY/ROBERT SIMMON

Four major global surface temperature analyses show that Earth has warmed since 1880, with most of this warming occurring since the 1970s.

The greenhouse effect is a natural process where greenhouse gases absorb and trap heat radiating from the Earth's surface.



ORIGINAL IMAGE: WILL ELDER, NATIONAL PARK SERVICE

Why is Climate Changing?

Changes in climate are driven by many factors. These factors include ***solar radiation***, ocean composition, ***greenhouse effect***, ***albedo*** effect, continental land arrangement, volcanic eruptions, ***fossil fuel*** combustion, and land-use change. Historically, the Earth has experienced 100,000-year cycles of ice ages and warmer periods, mostly due to changes in solar radiation. While natural forces explain historical climate shifts, those same factors do not account for the changes that are now being observed. Recent ***models*** of climate suggest that both natural and human-caused changes are responsible for recent increases in global temperature. Both the U.S. Climate Change Science Program (2006) and the Intergovernmental Panel on Climate Change (2013) agree that human activities, particularly increases in ***greenhouse gases***, are influencing the climate system. Greenhouse gases include the following:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)
- Water vapor (H_2O)

The Section I Overview contains a list of assumptions or confusions that your student may have regarding the causes of climate change.

The levels of greenhouse gases affect Earth's energy balance though the greenhouse effect—a natural process where greenhouse gases absorb and trap heat radiating from the Earth's surface. Measurements from ice core samples representing the past several thousand years indicate that until the late 1800s, CO_2 levels in the Earth's ***atmosphere*** had been fairly stable at about 280 parts per million (ppm). In summer of 2013, the daily average CO_2 level exceeded 400 ppm, which is a 40 percent increase from preindustrial levels (Bala, 2013). Researchers have noted that the rise in greenhouse gases coincides with rises in average global temperatures in the past. The Earth's atmosphere may have contained more than 400 ppm of CO_2 3 to 5 million years ago, and scientists estimate the global average surface temperature at that time was 2 to 3.5° C (3.6 to 6.3° F) higher than in the early 1800s (NAS and RS, 2014).

What Will Happen in the Future?

Because the global climate is a complex ***system*** and because there are many possible changes to the factors that increase greenhouse gases and temperature, firm predictions about the impacts of climate change are not possible. Climatologists use climate models to make ***projections***, which describe how future climate is expected to respond to various scenarios with the factors that might affect climate change, such as population growth, ***greenhouse gas emissions***, and land development patterns.

An increase of a few degrees in temperature is likely to have a variety of effects around the planet. While the polar regions are experiencing warmer winters, less sea ice, and glacial retreat, the equatorial regions are experiencing less temperature change. This is mainly because of a ***reinforcing feedback loop*** related to ice and albedo. Snow and ice in the Arctic reflect the sun's energy back to space, and as warmer temperatures cause snow and ice to melt, the darker exposed rock and water absorb more heat. In this cycle, temperatures continue to increase and snow and ice continue to melt. This reinforcing feedback continues and results in amplified warming in this region of the world. More heat in the atmosphere also will mean more ***evaporation*** from the planet's surface, which can reduce soil moisture and increase drought in some places and increase rainfall and extreme storm events in others. Changing temperature and precipitation may change ocean and atmospheric currents, creating new weather patterns with potentially welcomed, disastrous, or unanticipated effects depending on location. Changes in temperature and precipitation on the land are likely to bring about changes in the frequency and intensity of storms, including hurricanes and tornadoes. Plants and animals that currently live at the edge of their ranges may find the changing environment no longer meets their needs. Some populations may be able to migrate or shift; other populations may become smaller.

Through the 21st century, the southeastern region is expected to see increases in temperature, both increases and decreases in precipitation, and increases in the frequencies of major hurricanes. In particular, coastal communities in the region are threatened by sea level rise. Warmer temperatures can lead to more ***invasive species***, greater risk of ***wildfire***, and losses in forest ***productivity***. At the same time, increased levels of atmospheric carbon dioxide may benefit trees by increasing ***photosynthesis,*** if the other factors do not limit tree growth. The immediate impacts on forest ecosystems and agriculture are of great concern to many decision makers, researchers, resource managers, and farmers. Additionally, the long-term impacts may affect everyone through the availability and price of agricultural and forest products.

Why Doesn't Everyone Agree?

Climate scientists are confident that global warming is occurring, so why do people disagree about this issue? Of course the issue of climate change is complex and multifaceted, which makes it a difficult topic to explain and understand. Some people simply don't have the information to enable them to agree; they are appropriately confused and have a lot of questions. Some people have never had an Earth science class and

The **Explaining the Evidence** presentation allows you to explain areas of disagreement and why they exist. The **Analyzing Perspectives** student pages give students an opportunity to work with these ideas.

JOHN SEILER, VIRGINIA TECH

don't have background to understand some climate concepts. Without understandable explanations, it is easier to stick with what we have experienced in our lifetimes—a relatively stable climate that varies more from summer to winter than from year to year.

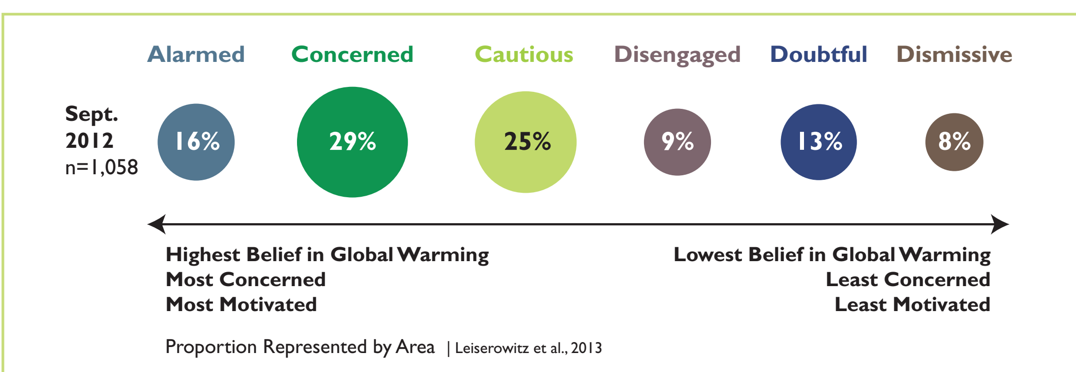
Others might understand the information and even acknowledge that changes are likely, but because they do not like or are uneasy with the possible solutions or social changes involved in mitigating or adapting to climate change, they find it easier to downplay the problem. Our economic dependence on fossil fuels to power industries and communities makes our entire nation vulnerable to changes that might occur with carbon emission policies, and some people who worry about the implications of these changes may prefer to find reasons to ignore climate change. In addition, it is hard to convince people to invest in changes when the benefits of those changes are not immediate.

Some strongly held and diverse opinions across America make the topic of climate change different from other environmental challenges. At the root of these various perspectives is a simple fact of human information processing: we more readily perceive and accept information that matches what we already know. Teachers demonstrate this every day by reminding students of previous lessons and experiences so that the new lesson "fits." Given a great deal of information, we are likely to pass over the information that doesn't fit our mental models and focus on the bits that reinforce our ideas. Thus, it is challenging to provide information to people who disagree with it, since they may not hear it or want to think about it.

This selective perception makes it possible for people to have partial information about climate change. By having only part of the story, people may arrive at conclusions that are only true some of the time and are not supported by all the evidence. The homework exercise for this activity helps students recognize some of these challenges.

When people don't have the time to learn about climate change, they are likely to accept the ideas of the political leaders and influential people they trust. Those leaders, like the rest of us, may only accept or understand some of the information, may have reasons to not support actions that address climate change, or may have beliefs about religion that conflict with the assumptions or conclusions of climate scientists. All of these factors contribute to the variety of opinions about the causes of climate change. Yale and George Mason universities have been conducting opinion polls with the general public over several years and have identified six different categories of beliefs. Although the percentage of the population in each category changes slightly with each new survey, there are people who are alarmed and concerned about the problem, people who are confused or not interested in learning more, and people who doubt climate is changing or are convinced that we should not make any changes to accommodate what they consider natural shifts in temperature. Your students'

Yale and George Mason universities have conducted opinion polls with the general public and have identified six different categories of beliefs about climate change.



parents probably fall into all six categories. The Background section of this module includes information about addressing climate change in the classroom and provides tips for working with students, parents, and administrators who may have varying viewpoints. The student exercises in this activity and the other activities in this module are designed to help you provide science-based information, allow students to understand these concepts and debate the interpretations, and engage them in thinking carefully and completely about climate change.

Exploring Solutions

Information about climate change is important and interesting, but students also will likely want to know that there are people, communities, organizations, and nations who are currently doing something about the problem. Rather than being fearful of the future, students can adopt a problem-solving approach to climate change. For instance, in order to address climate change, community and business leaders must first consider what is likely to happen in the future. If the changes are projected to be bad and the risk of these changes occurring is high, then communities may be motivated to take action to reduce risk. If the changes are projected to happen to people living far away or to future generations, then communities may focus their discussions on obligations to other people and the degree to which those obligations should change current behavior with regard to climate change. These discussions could focus on the essence of ***sustainability*** by considering how our decisions might affect the quality of life for future generations.

Most climate change ***mitigation*** strategies involve reducing emissions or increasing sequestration of greenhouse gases, mostly methane and carbon dioxide. By understanding the sources of these gases in the atmosphere, people can think about how to move these compounds somewhere else, or not produce them in the first place. For instance, society could decide to increase energy efficiency to reduce combustion of fossil fuels as well as reduce reliance on products or systems that currently depend on fossil fuels. Some communities, such as Aspen, Colorado, are already taking action to help people reduce energy consumption with improvements in public transportation and building efficiency. In addition, churches and businesses are participating in programs such as the "10% Challenge" to encourage their members to conserve resources, reuse products, and reduce energy use. This program provides the tools and the information necessary to conserve energy at home and at work by encouraging people to calculate their current annual greenhouse gas emissions and pledge to take some action to reduce these emissions by at least 10 percent.

Producing energy without fossil fuels, but with ***renewable resources***, will help reduce atmospheric carbon. A great deal of information is available about ***biomass***, nuclear, solar, and wind power, and some communities have already explored and implemented these technologies. For example, communities in Kansas are using wind energy, and communities in Vermont using wood to produce power and electricity.

In addition to reducing the amount of carbon released into the atmosphere, actions that can increase forest cover can help sequester carbon. For example, solutions may include ***reforestation*** and ***afforestation*** projects, managing forests to optimize ***carbon sequestration***, and avoiding large wildfires through appropriate ***vegetation*** management. Technologies that capture and store carbon are also being developed, which might allow nations to continue to burn some fossil fuels. But in the end, it may be important for students to consider larger questions, such as these: What amount of resource use allows us to be content? What contributes to happiness? How many of us can the Earth support? How can we best protect the interests of future generations?

The nuanced details of these solutions will make them appropriate in some situations and

The **Exploring Solutions** presentation could be shown on the same day if the first portion goes quickly, or it could be saved for a second period. After explaining mitigation and adaptation, several examples of real communities taking action are provided. The role-play activity in Part B allows students to identify community members with different ideas about climate change and discuss potential solutions they might take.

TEACHERS SAY …

We did a school-wide survey to determine if students knew anything about global warming. It turns out they were more knowledgeable than I anticipated.

—Honors and AP Biology Teacher, Florida

not in others. The simple strategy of eating less or different types of meat to reduce greenhouse gas emissions is a good example. Consider just a few of the factors that go into the production and transport of beef. Cows that are raised in feedlots are fed corn grown with fertilizers made from fossil fuels. The meat is shipped by trucks and trains across the continent, which requires more fossil fuel. Additionally, cows emit large amounts of methane during digestion. In general, the system of producing meat depends on petroleum and produces greenhouse gases. Eating beef from cows raised on a local pasture may use less fossil fuel. However, if this meat is more expensive, people may be discouraged from buying it. Another option is to eat less beef. The choices around what to eat are laden with cultural values that form different priorities as people decide what is most important to them: greenhouse gases, meat, or money. In Section 4: Life Cycle Assessment, the pros and cons of ***product life cycles*** can be explored in more depth by students.

In addition to considering how to reduce atmospheric carbon, communities around the world are planning and implementing climate change ***adaptation*** strategies. This process involves understanding projected climate impacts, assessing human and natural systems that are at risk of negative impacts, and determining ways to lessen those impacts. Adaptation strategies can take place in advance (by planning before an expected impact occurs) or in response to changes that are already occurring. Adaptation projects may take the form of new infrastructure, health programs, disaster preparedness, or agricultural and forestry practices.

Teaching This Content

This activity is designed to help students who may not have taken an Earth science course or been exposed to the science behind climate change. It is a complicated topic, but because the evidence is straightforward and compelling, the presentation can be coherent and helpful. The evidence can also be used to explore the process and nature of science, the development of competing hypotheses, and the variety of ways people can develop misconceptions.

While the process of science may occur without emotion, the implications of climate change are full of positive and negative attitudes. Policy changes, technological

Systems Thinking Connection

IN THIS ACTIVITY, students learn about the importance of understanding their own observations and experiences within the context of sound science. In the context of climate change, sound science supplements our observations and helps us understand the world. For example, some might be tempted to interpret a particularly warm day in January to be evidence for climate change or a cold day in late spring to be evidence against climate change. Scientific data help us understand long-term trends, not only of temperature, but also of atmospheric concentrations of greenhouse gases or rates of ***deforestation***, for example. With this information, we can explore how these variables affect each other over time. One of the important habits of a systems thinker is to focus on patterns of change rather than specific events. That is possible if we use and understand the data that scientists make available.

The concept of scale provides another way of considering this shift in thinking. Systems thinkers learn to evaluate an issue at multiple scales. At the finest scale, we might consider molecular properties of carbon dioxide or methane, which may involve interactions taking place in a fraction of a second. At the broadest scale, we might consider interactions between the Earth and the sun, which can involve cycles spanning millennia. Understanding climate change requires understanding how these various interactions happen at different levels of scale.

We have some experience doing this already. We know that as a year progresses from January to June, the weather will warm up in North America. However, no one expects every day during that period to be warmer than the last. We experience a cold snap in April without assuming that the general warming trend has reversed. The cold snap is due to interactions happening at a finer scale than the annual cycle of seasons. Two additional exercises to practice systems thinking skills are described in the Systems Enrichment Exercises section.

advances, and behavior changes are potential solutions that students can explore and debate. Communities are finding creative and meaningful solutions, but they tend to be more complex than simply recycling, which is often the answer that students suggest. By understanding climate change implications, students and everyone—including businesses, agencies, municipalities, and industries—can play a role in strategies to mitigate and adapt to our changing climate. Instead of being overwhelmed or depressed with the reality of change, students may be inspired to join those who are creating change.

The role-play in Part B is an opportunity for you to help students apply information about climate change and varying perceptions about the issue as they discuss potential community actions. If your students are not keen to play these roles, you can instead facilitate a discussion where students become a city council and consider the different perspectives being presented.

Getting Ready

The Activity 2 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section1/activity2).

Download the Explaining the Evidence and Exploring Solutions presentations from the Activity 2 webpage and review the presentations, background information, and presentation notes to decide how much you wish to present.

Consider whether to conduct Part A with student groups as suggested or to assign one or two student pages as homework. When students return to class, you can ask for volunteers to share how they rewrote the conclusions to be more accurate. See Modifications for additional options. Make copies of student pages after determining how you will conduct Parts A and B.

Doing the Activity

Part A: Climate Science and Analyzing Perspectives

1. Begin by explaining to students that people have different levels of knowledge and different viewpoints on climate change. Explain that some information we hear or read is based on scientific evidence, while other information is based on opinions or beliefs, which may or may not be supported by scientific evidence. You might say, "Since we are in a science class, our focus will be to learn how most climate scientists understand climate change. We will also discuss the range of opinions held by the public because this will help us consider potential actions that communities might take to reach agreement in order to implement adaptations or mitigations."

2. Distribute the Fact or Fiction student page. Ask students to read the statements and judge which statements they think are supported and which statements they think are unsupported by scientific evidence. Once students have completed the student page, ask them what they thought about the statements. Was it easy or difficult to decide the answers? Have they heard some of these statements about climate change in the news or in class or from friends or family?

3. Provide an overview of climate change science and why there are multiple perspectives using the Explaining the Evidence presentation. You are welcome to modify the presentation or supplement it with another resource.

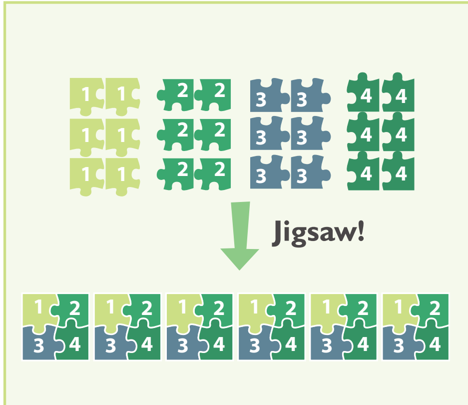
4. Organize the students into four equal groups. Give each group copies of one of the Analyzing Perspectives student pages (one per student). Explain that each group has been given a different short paragraph about climate change to read. As a group they should answer the questions to assess

TEACHERS SAY ...

I got students to buy in by showing the Climate Reality Project Video.

—Earth Science Teacher, Florida

When using the jigsaw technique, students begin in groups and focus on one topic. The students then "jigsaw" and form new groups, which allows them to share information and learn about all of the topics.



ORIGINAL IMAGE: ELLIOT ARONSON, WWW.JIGSAW.ORG

the paragraph and conclusion. Students should discuss the questions before writing the answers and rewriting the conclusion. Visit each group as they are completing the task and ask students to explain their thinking about their conclusions and how they rephrased the conclusions to better represent the science about climate change. Help the groups arrive at science-based conclusions. Answer keys are available on the Activity 2 webpage.

5. Reform the groups using the jigsaw technique. Ask students in each group to count off so that each person within the group has a different number. The students should then create new groups according to their numbers. Each new group should contain at least one member of each old group. In the new groups, ask each student to explain the problem with the initial conclusion, why someone might arrive at that conclusion, and how the statement was revised to be more accurate.

6. In a class discussion, review some of the common pitfalls of the conclusions the students assessed.

- If these conclusions don't represent the scientific consensus about climate change, why do some people believe them?
  People may have partial or inaccurate knowledge about the issue. It is easy to focus on one piece of evidence and miss others. People hear, remember, and understand information that makes sense to them. They may discard or not pay attention to more complex or frightening information. People associate with friends and relatives who agree with what they think, so it is easy to confirm their ideas and hard to question them.
- Besides scientific knowledge, what other things do you think influence the way people feel about climate change?
  People might listen to opinions about climate change that are conveyed through the media, family, friends, and community leaders, and these people filter information through their views of the world, values, fears, hopes, and beliefs (political, religious, and cultural).

Part B: Role-play

1. Explain that despite their different perspectives, it is still important for people to work together in a community. Let them know that during this exercise, they will have the opportunity to practice talking to people with different perspectives.

2. Use the Exploring Solutions presentation to share information about the ways communities and nations are changing behaviors and adapting to climate change. Remind students of the different perceptions people have about this issue.

3. Ten role cards representing a range of views about climate change are provided so you can select at least the most relevant roles for your local context and for the number of students in your class. We suggest you select at least one role from each of the four categories to ensure that a diversity of perspectives is represented in each student group. Create groups of students based on the number of role cards you select, giving each student one role card and a copy of the Role-play Guide. Explain the scenario to students and ask them to read their role and complete the My Role box before they begin. It may be challenging for students to take on a new role, especially if the position is not one they agree with. Consider providing additional time for students to think about their role so they can better understand the motivations behind certain attitudes and positions.

4. Explain the process of a role-play. Each student will convey a role to help the group realize the variety of perceptions and opinions that might exist in this community. The point of the exercise is for everyone to practice working with people who hold different beliefs and opinions. Help students think about the ways they can make sure they all stay in their roles and remain civil toward each other. Ask for volunteers in each group to be responsible for keeping the group on task, for making sure everyone has a chance to speak, for recording notes on page 2 of the Role-play Guide, and for keeping time. Groups may find they are more productive if they can use the white board or newsprint and markers.

5. Answer any questions about the scenario (each group is developing recommendations for Centerville's mayor to address climate change) and remind students that the actions they develop and support during the exercise should be consistent with their assigned roles. Explain how the groups should use the criteria on the Role-play Guide to assess each suggested action. Rating each criterion allows students to debate the relative advantages of an action that may be very effective, but not very practical or may cause other problems. In other words, actions will vary by criteria, and the committee should take all of those components into account. Students may realize that it is easier to obtain agreement on the least effective actions. You might ask them if that a useful way to begin making progress, or does it waste time in the long run? Provide the following timeframe for the role-play:

- 5 minutes: Each person introduces himself/herself in the assigned role and provides one idea for the community to address climate change.
- 5 minutes: The group takes one idea and rates it with the criteria on page 2 of the Role-play Guide.
- 15 minutes: Given the diversity of opinions in their community, the group chooses three other ideas and rates them.
- 5 minutes: The group discusses the rankings and selects one recommendation for the mayor.

6. Rotate among groups to ensure students are on task. Here are some questions to ask if a group is stuck.

- Are there some actions that most of you can agree would be worth doing in Centerville?
- For those you disagree upon, what is it about the action that is causing disagreement? Can some aspect of the action be modified or improved to make it more agreeable?
- Which action is most suitable for the community?

7. Once all the groups are finished, ask each group to present its recommendation to the class and explain how the decision was reached. Students should explain what the action is and how it relates to climate change, what members of the community will be affected by the action, and how or where it will be implemented.

8. Lead a class discussion about the experience of the role-play, the advantages and disadvantages of working with people with different perspectives, and how the students think communities might talk about climate change. You might ask the following questions:

- Which two roles were the least likely to agree on climate solutions? What about those perspectives makes it difficult to agree? How were you able to overcome this challenge?
- How well were you able to play your role? What made it difficult or easy?
- What are some reasons people may support climate change solutions even if they initially disagree about the issue?

TEACHERS SAY ...

The presentations fostered some excellent discussions, which in turn provided the perfect transition into the role-play portion of the activity.

—AP Environmental Science Teacher, Florida

TEACHERS SAY …

My students truly enjoyed the role-playing. Again, I was surprised in their eagerness to participate. It was much better than taking notes.

—Earth and Environmental Science Teacher, North Carolina

- What are the advantages and disadvantages of a group of people agreeing to an activity but not agreeing on the reasons for the activity?
- Is the best action the one that is rated "high" for the most criteria, or is it the one that is not rated "low" for any criteria?

9. Systems Reflection: When discussing the experience of the role-play, instructors may want to emphasize that exploring a diversity of perspectives helps groups consider more elements of a system, and often a bigger system. In what ways might these additional aspects of the system help a group arrive at a better solution?
New and different perspectives can add variables to the system that we may not have considered at first. Systems thinkers can use these perspectives to alter their own perspective or the boundaries and scale of the system under consideration. Many of the perspectives in this role-play are not wrong, but they are incomplete. Students should be able to identify the faulty assumptions. For example, past climate changes are not predictive of future changes, since the current rate of change is much faster than it has been historically. When exchanging ideas with people who hold different perspectives, students should remember that these people might offer important insights or concerns that they had not previously considered.

10. As you wrap up this activity, ask students to look again at the Fact or Fiction statements about climate change from the beginning of the lesson and confirm what statements are supported by evidence. Review the answers with students (see answer key on Activity 2 webpage), and make sure to clarify any remaining questions or misunderstandings. The complexity of the issue makes it challenging to talk about climate change in simple terms, and it is easy for brief statements to be misleading. These challenges and others make it likely that people will have different ideas about climate change, which may be reinforced by political positions or existing beliefs. The role-play exercise, however, should make it clear that even those who disagree about climate change can agree on productive and important steps they can take within their community to conserve resources and improve well-being.

Modifications

Consider shortening the Examining the Evidence presentation to the evidence that your students will most easily understand. Students can check their work on the Fact or Fiction student page as you go through the Examining the Evidence presentation.

You can reduce the number of Analyzing Perspectives student pages that you use, and you may wish to use **Activity 7: Carbon on the Move** prior to Emily's Perspectives on the Natural Causes of Climate Change student page.

In Part B, students could look for solutions fitting to their roles as you review the Exploring Solutions slide presentation.

Rather than dividing into small groups to role-play the committee, you could also keep the class together and facilitate a discussion with the class as the committee.

Rather than play roles, students could report on the various perspectives by reading several cards and explaining them. They can still generate potential actions and discuss the advantages and disadvantages based on the criteria on the Role-play Guide and the diversity of perspectives in the community. If the rating criteria are too challenging, consider reducing them to technical feasibility and expense (cost efficiency).

Rather than a discussion, students could be given a role card and asked to provide a written response that this person might use to promote a climate change action.

Systems Enrichment Exercises

SIMPLY FOCUSING ON PATTERNS IS NOT ENOUGH TO UNDERSTAND THE BEHAVIOR OF COMPLEX SYSTEMS. Consider our relationship to computers (or cell phones). You can use a computer without having any idea as to how it really works. You push a button, click the mouse, tap on the keyboard, and off you go. But what do you do when the computer acts in an unexpected way? Most of us are stumped by any computer problem that requires more than turning the computer off and back on.

To really understand why a computer is acting in an unexpected way, you have to learn more about how it works. The same idea holds for complex systems. In order to understand how complex systems work, it can be useful to think about the variables that make up the system (called stocks) and the relationship between those variables (called flows). Even systems that are familiar to us, such as a bathtub, can show unexpected behavior unless we think of them in terms of stocks and flows.

In the **Bathtub Dynamics** systems exercise, students graph the change over time of the volume of water in a bathtub. After working through the graphing exercise, students learn how understanding a bathtub can help them avoid a common confusion regarding climate change. For more details, see the slide presentation, instructions, and worksheet on the Activity 2 webpage.

Another systems exercise, **Riddle Me This,** enables students to explore the speed at which changes in complex systems can occur due to reinforcing feedback loops in the system. Reinforcing feedback can lead to changes that happen much faster than people expect when one variable increases as a consequence of its value—a pattern called ***exponential growth.*** This exercise contains three puzzles to help students practice thinking about exponential growth. It is also found on the Activity 2 webpage.

Several additional climate change information and education resources are found on the module website (https://sfcc.plt.org).

Enrichment

Have students create a few questions that they could use to interview at least three adults (e.g., family, neighbors) to learn more about other people's knowledge and views on climate change. Students should compile their data and summarize what they learned in a short paper.

Additional Resources

Climate Change: Evidence and Causes
National Academy of Sciences and the Royal Society, The National Academies Press, 2014
http://www.nap.edu/catalog.php?record_id=18730
This short pdf booklet provides clear answers to 20 common questions and background basics to climate change science.

Climate Change: Evidence, Impacts, and Choices: Answers to Common Questions about the Science of Climate Change
National Research Council, 2012
http://nas-sites.org/americasclimatechoices/files/2012/06/19014_cvtx_R1.pdf
This booklet summarizes the current state of knowledge about climate change, explains some impacts expected in the 21st century and beyond, and examines how science can help inform choices about managing and reducing the risks posed by climate change.

Climate Literacy Guidelines: The Essential Principles of Climate Science
U.S. Global Change Research Program, 2009
www.globalchange.gov/resources/educators/climate-literacy
This guide presents information for individuals and communities that want to learn about climate, impacts of climate change, and approaches to mitigation and adaptation.

The Climate Reality Project, Videos
The Climate Reality Project
http://climaterealityproject.org/video/
This website has several videos about climate change, carbon emissions, and

Students will likely be interested in knowing what types of actions can be implemented by communities and organizations to address climate change.

CENTRALINA CLEAN FUELS COALITION

solutions. Be sure to check out "Climate 101 with Bill Nye" to get a brief explanation of climate change and its potential effects on our planet.

Misconceptions about Science
University of California Museum of Paleontology
http://undsci.berkeley.edu/teaching/misconceptions.php
This portion of the Understanding Science website is dedicated to addressing misconceptions about the scientific process and includes explanations of some scientific terms that students might misunderstand.

Regional Climate Trends and Scenarios for the U.S. National Climate Assessment
U.S. Department of Commerce NOAA Technical Report
http://www.nesdis.noaa.gov/technical_reports/NOAA_NESDIS_Tech_Report_142-9-Climate_of_the_Contiguous_United_States.pdf
This document is one of the series of regional climate descriptions designed to provide input that can be used in the development of the National Climate Assessment.

Skeptical Science: Getting Skeptical about Global Warming Skepticism
John Cook, Global Change Institute at the University of Queensland
www.skepticalscience.com
This website reviews scientific, peer-reviewed literature to help explain climate change and to address common misconceptions about climate change.

Southeast Region Technical Report to the National Climate Assessment
Keith Ingram, Kirstin Dow, and Lynne Carter; 2012
http://downloads.usgcrp.gov/NCA/Activities/NCA_SE_Technical_Report_FINAL_7-23-12.pdf
This report summarizes the scientific literature that addresses climate impacts for the Southeast United States with a focus on literature published since 2004, and includes a chapter that specifically examines climate change and forests.

Teaching Controversy
Mark McCaffrey, 2012
http://www.nestanet.org/cms/sites/default/files/journal/Fall12.pdf
The author discusses why teachers should

not present climate change as a "theory" open for debate, but instead should focus on helping students understand climate change and the supporting scientific research. This article is part of a special issue on climate change education in *The Earth Scientist* published by the National Earth Science Teachers Association.

Yale Project on Climate Change Communication
Yale University
http://environment.yale.edu/climate
This website provides several reports, videos, and other resources that help explain research related to public knowledge and perceptions of climate change.

Your Warming World Interactive Map
New Scientist
http://warmingworld.newscientistapps.com
This interactive map allows users to click on any location on the planet and see a graph that shows differences in surface temperatures from 1880 to the present, relative to average temperatures for the three decades from 1951 to 1980.

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Fact or Fiction

NAME DATE

Please circle whether you think each of the following statements is or is not supported by scientific evidence. You can also circle that you do not know.

1. The Earth's climate is changing due to global warming.

   Supported by science Not supported by science I don't know

2. Climate change will affect regions of the Earth differently, with some areas becoming wetter and others becoming drier.

   Supported by science Not supported by science I don't know

3. The impacts of climate change will not really affect people or the systems we depend upon (such as food, water, places to live, etc.), just temperature.

   Supported by science Not supported by science I don't know

4. Sea level rise is mostly caused by melting icebergs and ice sheets.

   Supported by science Not supported by science I don't know

5. Burning fossil fuels is the only cause of global warming.

   Supported by science Not supported by science I don't know

6. Seasonal melting of Arctic Sea ice and glaciers is evidence of climate change.

   Supported by science Not supported by science I don't know

7. The greenhouse effect is a natural process that supports life on Earth.

   Supported by science Not supported by science I don't know

8. Many climate scientists disagree about the causes of climate change.

   Supported by science Not supported by science I don't know

Emily's Perspective on the
Natural Causes of Climate Change

NAME DATE

Imagine your friend Emily tells you she has been learning about the causes of climate change from reading and listening to news reports, searching the Internet, and talking with friends. All the information she has learned is **accurate and science-based.** However, the conclusion Emily makes using this information is **NOT** supported by science. Here's what Emily said.

Climate has changed in the past, and those changes were caused by several factors that are natural. Natural factors include variations in volcanic eruptions, solar flares, greenhouse gas concentrations, and other factors. In particular, concentrations of greenhouse gases, like carbon dioxide, have naturally fluctuated over time. The amount of carbon dioxide emitted from human activities is a tiny fraction of the total carbon cycling through the atmosphere, land, and oceans. Natural carbon dioxide emissions are 766 billion tons per year; human carbon dioxide emissions are only 20 billion tons per year. This current fluctuation in climate is similar to historic climate changes because human activities have not added that much carbon dioxide to the atmosphere. Therefore, climate change is a natural process that human activity is not impacting.

1. What were your initial thoughts as you read the paragraph?

2. What are the assumptions Emily makes to arrive at her conclusion?

3. What science-based information is relevant, but missing, from what Emily learned?

4. What would you say to Emily? REWRITE the conclusion to be more accurate, based on the additional information that challenges the conclusion.

Jamie's Perspective on the

Human Causes of Climate Change

NAME DATE

Imagine your friend Jamie tells you he has been learning about the causes of climate change from reading and listening to news reports, searching the Internet, and talking with friends. All the information he has learned is **accurate and science-based.** However, the conclusion Jamie makes using this information is **NOT** supported by science. Here's what Jamie said.

Many factors affect the global climate of the Earth. The key factor to consider regarding climate change is carbon dioxide. By burning fossil fuels, such as oil, natural gas, and coal, we have increased the amount of carbon dioxide in the atmosphere and changed where the carbon can be found. The level of atmospheric carbon dioxide is higher now than it has been over the past 800,000 years. This increased amount of carbon traps more of the heat radiated from the Earth's surface, which amplifies the greenhouse effect. In addition, land-use changes have altered vegetation patterns around the globe. Deforestation has resulted in fewer trees to remove and store carbon through photosynthesis. These land-use changes have also affected levels of atmospheric carbon. The impact of human activities on carbon in the atmosphere and ocean is so large that it completely overshadows any natural causes of climate change. Therefore, while natural factors have played a role in the past, current and projected climate changes are only the result of human activities.

1. What were your initial thoughts as you read the paragraph?

2. What are the assumptions Jamie makes to arrive at his conclusion?

3. What science-based information is relevant, but missing, from what Jamie learned?

4. What would you say to Jamie? REWRITE the conclusion to be more accurate, based on the additional information that challenges the conclusion.

Micah's Perspective on the

Greenhouse Effect

NAME DATE

Imagine your friend Micah tells you he has been learning about the greenhouse effect from reading and listening to news reports, searching the Internet, and talking with friends. All the information he has learned is **accurate and science-based.** However, the conclusion Micah makes using this information is **NOT** supported by science. Here's what Micah said:

Several gases contribute to the greenhouse effect, including carbon dioxide (CO_2), methane (CH_4), ozone (O_3), and nitrous oxide (N_2O). These gases absorb heat radiating off of the earth and trap that heat within the atmosphere. Greenhouse gas emissions have increased since the Industrial Revolution, which has amplified the greenhouse effect. Scientists have noted that this rise in greenhouse gases coincides with rises in overall global temperature. According to existing climate models, global temperatures are expected to rise anywhere between 2 and 11.5 degrees Fahrenheit by the year 2100. Results of global temperature changes of this magnitude include sea level rise, increase in ocean acidity, decrease in snowfall and permafrost, and changes in precipitation. The greenhouse effect is a negative and harmful process because it is warming the planet and creating climate change.

1. What were your initial thoughts as you read the paragraph?

2. What are the assumptions Micah makes to arrive at his conclusion?

3. What science-based information is relevant, but missing, from what Micah learned?

4. What would you say to Micah? REWRITE the conclusion to be more accurate, based on the additional information that challenges the conclusion.

Jayden's Perspective on the

Effects of Climate Change

NAME DATE

Imagine your friend Jayden tells you she has been learning about the effects of climate change from reading and listening to news reports, searching the Internet, and talking with friends. All the information she has learned is **accurate and science-based.** However, the conclusion Jayden makes using this information is **NOT** supported by science. Here's what Jayden said.

After analyzing climate observations, measurements, and data collected around the world, most climate scientists agree that the average surface temperature of the Earth is increasing. This is known as global warming. Most scientists also agree that human activities, which are increasing atmospheric levels of greenhouse gases, are partially responsible for this warming. As a result, the entire planet is and will continue to warm in the years to come. This warming will affect weather patterns around the world, changing climate averages and causing extremes in temperature and precipitation. The greenhouse gases that are causing global warming are found in the atmosphere, and the atmosphere surrounds the entire globe equally. Therefore, everywhere on Earth will be hotter and drier.

1. What were your initial thoughts as you read the paragraph?

2. What are the assumptions Jayden makes to arrive at her conclusion?

3. What science-based information is relevant, but missing, from what Jayden learned?

4. What would you say to Jayden? REWRITE the conclusion to be more accurate, based on the additional information that challenges the conclusion.

Climate Change Role Cards (1 of 2)

CATEGORY 1	**CASEY.** You are very concerned about climate change; you believe it is happening and that it is caused mostly by human actions. In particular, you know that burning coal, natural gas, and oil for energy production is increasing the amount of carbon dioxide in our atmosphere, which is causing climate change. You believe that people need to take immediate and substantial action to reduce atmospheric carbon dioxide and to adapt to projected changes in temperature, precipitation, and weather events. This is not a political issue to you but a matter of maintaining life on Earth. You heard about a tree planting campaign and are interested in starting something similar in your town.
	MORGAN. As a religious youth leader in your community, you have strong faith and believe that God created the world and will take care of the Earth. At the same time, you believe that humans are responsible for their actions. You believe that climate change is happening and it is mostly due to human actions. And, you are greatly concerned about the impacts of climate change in your community, such as extreme weather and its effects on both people's health and the surrounding forests and wildlife. You have spent much time thinking about climate change and it is a big concern for you. You believe that we are obligated to leave future generations a healthy planet.
CATEGORY 2	**KENDALL.** You work for a local environmental organization called Carbon Sink. You are very concerned about climate change; you believe it is happening and that it is caused mostly by human actions. In particular, you know that burning coal, natural gas, and oil for energy production is increasing the amount of carbon dioxide in our atmosphere, which is causing climate change. You believe that people need to take immediate and substantial action to reduce atmospheric carbon dioxide and to adapt to projected changes in temperature, precipitation, and weather events. This is not a political issue to you but a matter of maintaining life on Earth. You heard about a campaign to reduce fossil fuel dependence and you are interested in starting something similar in your local community.
	JESSIE. You work for a small grocery store in your town. You believe that climate is changing due to a combination of natural causes and human activities. Humans are playing a large role in increasing and accelerating natural climate change. You think that practical solutions are needed at the local, regional, national, and global level. However, you are concerned that people might not be willing to make large behavior changes for benefits that will occur in the future. You think that climate change solutions need to have more immediate benefits so that people will be more likely to adopt them. For example, reducing fossil fuel use saves people money, reduces air pollution, and helps reduce atmosphere carbon dioxide.
	QUINN. You are a school teacher, and you believe that climate is changing as a result of natural causes and human activities. You understand that humans are playing a large role in increasing and accelerating natural climate change. You believe that educating youth about climate change is the most important way to change behavior, since one day your students will be making decisions and voting as adults. In your classroom, you teach about the scientific process and how scientists use data to make conclusions. You are also interested in community education programs that teach adults and families about the environment and sustainable solutions for environmental issues.

Climate Change Role Cards (2 of 2)

CATEGORY 3	**KRIS.** You believe that climate change is happening, but that the climate has been changing for a long time and humans have nothing to do with it. Therefore, there is no way for people to affect climate change because they have no control over the climate. This theory about human-influenced climate change is all part of a political agenda and scientists are supporting it to fund their research. We really shouldn't be spending so much effort researching causes and solutions for climate change. We should focus on people's ability to adapt to this new climate, for example, by changing food production strategies or by improving community preparedness and disaster response.
	HARPER. You have strong faith and believe that God created a perfect world and there is nothing humans can do to affect it. In your mind, climate has been changing for a long time and humans have nothing to do with it. Therefore, there is no way for people to affect climate change. This theory about human-influenced climate change is all media hype. We really shouldn't be spending so much effort researching causes and solutions for climate change. We should focus on people's ability to adapt to this new climate, for example, by changing food production strategies or by improving community preparedness and disaster response.
CATEGORY 4	**TAYLOR.** You believe that the science on climate change is not at all clear. The news reports are contradictory. For example, when there is a heat wave, the headlines read "Global Warming Effects Being Felt in the Southeast!" But when we have a colder winter than usual, the headlines changes to "Snow in the Southeast? Who Said the Climate is Warming?" There are scientists on both sides of the issue making different conclusions about whether it is happening, the causes, and the effects. Once the science has been settled, and the news media are consistent, you will be receptive to either side. You are just not sure that we should be taking action on climate change when there is so much that is still being debated.
	JORDAN. You work for an international company and have traveled to different countries. You believe that the science on climate change is not at all clear. The news reports are contradictory. But you do know that some countries are already doing a lot to adapt to climate changes and other countries are very vulnerable to future disasters. Floods, typhoons, and drought will affect developing countries more severely than they affect the United States. You are confused, but you also care about people around the world. But you aren't sure what you can do.
	SAM. You believe that climate change is happening but you are not sure whether it is due to natural or human causes. You are also unsure whether or not a change to the climate is a bad thing. You do not spend much time thinking about climate change, so it is not a big concern for you. However, you are greatly concerned about other environmental issues, such as air pollution in your city and its effects on people's health and the surrounding forests and wildlife. Also, you think natural resource conservation is a good idea to ensure both healthy environments and productive economies for future generations.

Role-play Guide (1 of 2)

Before the Role-play

SCENARIO

You are a resident in the medium-sized town of Centerville. Due to your knowledge and leadership, the mayor of Centerville has appointed you to the Climate Change Adaptation and Mitigation Council. The mayor is concerned about the potential impacts of climate change and recognizes that there are a variety of beliefs in the community. While you may not agree with all the climate change issues, you are interested in community well-being, environmental health, and a thriving local economy.

The task for committee members is to work together to find a solution to help the community address potential climate changes. First, brainstorm at least four potential actions. Then select the best idea based on the criteria provided on page 2 of this worksheet. Develop that idea into a more detailed action plan to present to the mayor. You want to find a way to support the community effort, even if you don't fully agree with the reasons some group members provide.

Read the scenario and your role card. Fill out the "My Role" box to prepare your introduction when the role-play begins. Remember, for this activity it is important for you to imagine you are the person described in your role card, even if you do not agree with that position.

MY ROLE

Name:____

Your ideas and opinions about climate change:

One initial idea for an action you are willing to support:

Role-play Guide (2 of 2)

In the left column, write the title of each action your group considers. Then, use the four criteria described below to discuss the advantages and disadvantages of each action. Rate each criterion as high, medium, or low and record the rating in the table. After discussing all the actions, compare them to one another and chose the "best" action for your community. The best action could be the one that has the most impact, the one that is the easiest to implement, or the one that is easiest to agree upon. Just be ready to justify your decision as a group!

CRITERIA					
	GHG Emissions Reduction Benefit	Technical Feasibility	Cost Efficiency	Community Acceptability	Additional Comments
ACTION 1:					
ACTION 2:					
ACTION 3:					
ACTION 4:					

Use the following criteria to evaluate the suggested actions for your community (American Public Transportation Association, 2011):

- **Greenhouse Gas Emissions Reduction Benefit:** Does the proposed action reduce greenhouse gases? In what way—by sequestering atmospheric carbon dioxide or by reducing emissions?
- **Technical Feasibility:** Does technology already exist to implement the proposed action? How easy is this action going to be to implement?
- **Cost Efficient:** How expensive will this action be? Will it result in long-term savings? How will the project be funded?
- **Community Acceptability:** How will citizens feel about this action? Who benefits from this action? In what ways? Who might be negatively impacted from this action? In what ways?

ACTIVITY

3 Atlas of Change

Students use the online resource, the Climate Change Atlas from the United States Forest Service, to explore the effects of climate change on the future distributions of suitable habitats for forest types, tree species, and bird species in the southeastern United States.

Subjects
Agriculture, Biology, Environmental Science, Language Arts

Materials
Student pages and presentations (see Activity Webpage link below); computers with Internet connection; flip chart, poster board, or butcher paper; colored markers or pencils; maps; ruler; scissors; tape or glue sticks; pictures of birds and trees; reference materials

Skills
Communicating, Comparing and Contrasting, Determining Cause and Effect, Interpreting, Predicting

Time Considerations
Three 50-minute periods and homework

Related Activities
Students should have an understanding of climate change (Activity 2) and the relationship between forests and climate (Activity 1). This activity can be followed with additional ways researchers are exploring forest changes (Activity 4) and forest managers are addressing climate change (Activities 5 and 6).

Research Connection
Researchers model climate change and use models to make projections of future conditions. Modeling is an important area of research when addressing complex systems.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section1/activity3

Objectives

By the end of this activity, students will be able to

- Explain how modeling is used to project climate change impacts, and
- Compare projected changes to suitable habitat for southeastern forest ecosystems or bird populations that result from using different climate models and scenarios.

Assessment

- Ask each student to write a summary of the posters responding to this prompt: How might climate change affect forest ecosystems and on what information do we base these ideas? Assess essays for understanding of models; climate; climate change; and range distributions of forests, trees, and bird species.

Background

Projected changes in ***climate***, such as temperature and ***precipitation***, are likely to impact forests in the United States. The trees and animals that are found in forested ***habitats*** may not be able to naturally adapt to rapidly changing climate conditions. As a result, researchers believe that forest ***ecosystems*** in the future will be made up of plants that can thrive in the new climate conditions; these will not necessarily be the same combination of plants that we see now. To help imagine how plants and animals might respond, researchers have created computer ***models*** that combine data from a variety of different factors to project the future climate. Models are tools that use datasets and mathematical equations to approximate processes and ***systems*** over time. They can only include what we know, so they are always being updated and changed.

Climate Change Atlas

Researchers with the United States Forest Service (USFS) are using models to examine the extent of potential ***climate change*** effects on forest ecosystems. Forest Service scientists have combined Forest Inventory and Analysis records for nearly 3 million trees and data on 38 environmental variables (e.g., average annual precipitation, mean July temperature, elevation) in the Climate Change Atlas to predict where a particular tree species or forest type will have suitable habitat by the end of the 21st century (Iverson, Prasad, Matthews, & Peters, 2008).

Additional background information, especially to introduce climate change, can be found in the **Section 1 Overview** and in **Activities 1** and **2**. Some teachers suggest using this activity to begin a unit on climate change.

The Atlas includes information on 134 species of trees in the eastern United States, which are grouped in ten forest type categories and are displayed on maps that can be accessed on the Atlas website. The forest types indicated on the maps are the dominant forest types found in the eastern U.S. There may be other nondominant forest types present in the area, but they are not displayed on the map. The seven forest types found in

Climate change is projected to affect suitable habitat for both tree and bird species, such as this Florida Scrub-Jay in the Ocala National Forest, Florida.

JOHN PUSCHOCK, U.S. FOREST SERVICE

the Southeast are described in the Southeastern Forest Types student page. You can find out more about the trees that grow in your area by talking to ***foresters*** and ***Extension*** agents; visiting an arboretum, park or forest; and accessing tree identification guides and websites (see Additional Resources). The ***biodiversity*** of each forest type depends on the environmental characteristics of that area and the history of disturbance and management in any particular place. As climate changes, the locations of suitable habitat for these forest types will also change. While it is interesting to imagine forests "picking up and moving" to a more suitable habitat, this is not accurate, as each organism may respond differently to climate changes. The amount of movement of a species will depend on where seeds fall and whether seedlings survive. This model shows where the climate will be appropriate for these forests types, not where the forests will be.

The animals that live in these forests will also be affected by climate changes. Many bird species, for example, are closely linked to particular stages of forest development or forest types because of their food and nesting requirements. Much like the forest ecosystems, the habitats of these bird species depend on specific environmental characteristics. Depending on how climate change modifies their habitat, these bird species might flourish or might decrease in population. Thus, scientists correlated 147 bird species with tree species in the Climate Change Atlas to track their relative habitat gain or loss (Matthews, Iverson, Prasad, & Peters, 2011). They used bird population data with 11 environmental variables and tree species potential change data to generate models of current and future suitable habitat.

Global Climate Models and Emission Scenarios

The Atlas relies on a wealth of data that scientists have been collecting for many years. Collecting and assembling existing environmental data is challenging but

TEACHERS SAY...

I thought the Atlas was wonderful. It has a lot of useful info!!

—Ecology Teacher, Virginia

possible, since these factors are observable and measurable. Scientists took records of rainfall, for example, and averaged them over a region to add existing precipitation data to the Atlas. Similarly, scientists sampled tree and bird species in forest plots and established sampling routes used for the North American Breeding Bird Survey to identify and measure the relative abundance of the species. Using such combined data, scientists can develop models of current habitat for tree and bird species.

To estimate how changes in future climate conditions may affect these species, scientists first have to model what those changes might be, which is also a challenge. The Atlas uses three global climate models to project changes to the climate:

1. Parallel Climate Model (PCM)
2. Hadley CM3 Model (Hadley)
3. Geophysical Fluid Dynamics Laboratory (GFDL) Model

These climate models are among the latest generation of numerical models to combine atmospheric, ocean, sea-ice, and land-surface variables to represent historic climate variability and then project future climate changes due to ***greenhouse gas emission*** levels. The three climate models represent a possible range of climate ***projections***, with PCM having a mild degree of change, Hadley having a large degree of change, and GFDL falling in the middle. Because these models use data from large-scale databases and algorithms that reflect global patterns, their predictions of local, specific changes are uncertain. Although the Atlas can be used to suggest potential futures for your state, the models are much better at conveying potential trends across the eastern U.S. They were designed to represent large-scale changes in climate.

Greenhouse gas emissions are important components of our changing climate. However, it is difficult to predict emission levels because such projections depend on national policies and decisions that individual people make. To show the range of possibilities, the Atlas applies two emission scenarios for each model:

1. High emission scenario, where few ***conservation*** efforts are taken to reduce atmospheric ***carbon dioxide***.
2. Low emission scenario, where significant efforts are taken to reduce atmospheric carbon dioxide.

Generally, the Hadley model under the high emission scenario (Hadley-High) shows a

TEACHERS SAY...

This activity demonstrates effective interpretation of models and how to use the established models.

—AP Environmental Science Teacher, Florida

NOAA CLIMATE PROGRAM OFFICE

Computer models combine data from a variety of different factors to project future climate.

The **Understanding Models** presentation on the Activity 3 webpage will help you introduce models and scientific uncertainty.

potential worst-case scenario (the highest emissions and greatest effects from climate change), while the PCM model under the low emission scenario (PCM-Low) shows a potential best-case scenario (the lowest emissions and therefore least effects from climate change). These two examples can be used to understand the range of possible outcomes. In addition, the Atlas includes results from both emission scenarios using an average from all three models. In total, you can view projected changes in eight combinations of models and scenarios. Based on which models are used as inputs, results for forest types, tree species, and bird species ranges will be impacted accordingly.

When scientists talk about uncertainty, they often use the term differently than it is used in everyday language. ***Scientific uncertainty*** is "the range of values within which the true value is likely to fall" (Understanding Science, 2013). All measurements contain some level of uncertainty. In all climate change models, uncertainty stems from several factors. Models are a simplified version of the world; they are not reality and, therefore, cannot encompass every aspect of a system. Most systems are more complex than scientific models can possibly account for, and interactions among variables can cause minor changes to be amplified over time, resulting in a wide array of model outcomes.

Climate scientists use many techniques to limit and account for uncertainty in their models. For example, they run models multiple times under varying conditions, observing how much the projected outcomes change. They also use different types of models. Confidence in models increases when several different types of models yield similar projections under a variety of conditions. That's why the Atlas has three climate models to explore. The resulting display of forest types shows broad conditions that may exist in the future. The agreement among all the projections represents changes that are most likely to occur.

Teaching This Content

This activity introduces students to tools and models as well as to some of their limitations. Students may express frustration at not having clear and certain predictions about the future, but the uncertainty built into the models also describes the many

Systems Thinking Connection

IN THIS ACTIVITY, students learn how to use a model of a complex system developed by forest and climate scientists. The model incorporates a variety of cause-effect relationships to make projections about how species are likely to be affected by climate change. When cause-effect relationships are simple, we can easily make reasonable projections about their future behaviors. For example, a good outfielder can watch a baseball being hit and move to where it will likely hit the ground. The possibility of wind gusts would introduce some uncertainty—not uncommon to complex systems—that would affect the ball's flight. Without the wind gusts, we can consider the ball and bat a simple system. Simple systems are more predictable because the variables show linear behavior. When behavior is linear, a small perturbation to the system will cause a small effect (i.e., small cause→small effect). For example, hitting the ball slightly harder will send it slightly farther.

However, as a result of their weblike, cause-effect structure, complex systems exhibit nonlinear behavior. With nonlinear behavior, a small perturbation may be absorbed by a system and cause little or no effect, or it may ripple throughout the system, causing an enormous impact. Also, these changes may take place immediately, or there may be a significant delay between a cause and the effects that follow. Consider the difference between poking a tennis ball and poking the person beside you. The distance the tennis ball will move directly depends on how hard you poke it. With the person, however, the possibilities are broader. He or she might ignore you, smile, become annoyed, or have a multitude of other responses that will involve far more outcomes than the tennis ball exhibited. This activity allows students to understand complexity through a climate computer model and see the types of nonlinear impacts that might result. Optional enrichment exercises that use other climate models are available on the Activity 3 webpage.

ways we can influence the future. What will happen depends on what we decide to do.

Students may also recognize that influencing changes in greenhouse gas emissions may require legislation as well as leadership from government and business sectors. A few people riding bicycles rather than driving cars will not make a difference, but changes that a majority of people make will determine if we are in the high or low emission scenario.

While students may feel sad that suitable habitat for some tree and bird species might not be expected to occur in their state in the future, changes in forest ecosystems are simply that—changes. Ecosystems are always changing. People assign value to those changes. Becoming ***resilient*** to future climate changes may mean learning to accept and adapt to ecosystem changes. Complications could arise, however, when people depend on species that no longer thrive in a particular area.

Getting Ready

The Activity 3 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section1/activity3).

Watch the "An Introduction to Climate Change Atlas: How Does it Work?" video, which is found on the Activity 3 webpage. Other U.S. Forest Service videos are available at www.nrs.fs.fed.us/atlas (see link in right column under Climate Change Atlas Videos). Decide whether your students would benefit from viewing some of these videos; at the least, we recommend the introduction to the Atlas.

Download and review the student pages to familiarize yourself with the Atlas and the activity. Please note that the Atlas websites were being updated in 2014. While the new websites can be accessed online, they are not fully functional yet. For this reason, the student page should be used only with the old website addresses (Tree Atlas: www.nrs.fs.fed.us/atlas/tree and Bird Atlas: www.nrs.fs.fed.us/atlas/bird/index.html). When the new Forest Service Atlas website is finished, we will create a second student page and post it on the webpage for Activity 3.

Download the Understanding Models presentation and review it to determine how much you wish to present to students. This provides an explanation of models, how they are tested, and why they can be different. The Atlas Guide presentation shows screenshots of the Atlas to help you guide students through the website as they complete the student page. This may be easier if you can project the presentation in a computer lab while students work directly with the website. That way they can follow along as you guide them through the site.Make copies of the student pages (one for each student).

Pilot teachers suggested introducing models and the Atlas in a computer lab on Day 1, assigning the WebQuest for homework, developing posters on Day 2, and using Day 3 to review posters and discuss the lesson. If your students cannot complete the WebQuest on their own, you will need another day in the computer lab. Our teachers also found it helpful to use the videos and slide presentations to become familiar with models and the website prior to teaching.

Doing the Activity

1. Remind your students that scientific models are used to represent complex systems. Models share many, but not all, characteristics with the systems they represent. As we learn more about our climate, the models will be improved. Ask students this question: What do you think the impacts of climate change will be on forest ecosystems? Discuss and record their ideas about the

TEACHERS SAY ...

I really enjoyed this and wish I had been able to spend more time on it.

—Ecology Teacher, Virginia

If you used the **Dynamic Systems Dance** from Activity 1, remind students that as one variable changes in a complex system, other variables change too.

TEACHERS SAY ...

The most beneficial measure of my students' understanding was the finished posters. They spent a lot time putting them together.

—Earth Science Teacher, Florida

ecological impacts of climate change so you can revisit them at the end of the activity. Ask students to describe the major types of forests in your state. If they are not familiar with their forests, consider introducing local forests with materials in the Additional Resources section and the Southeastern Forest Types student page.

2. Introduce models and how models are used to simulate processes and systems over time. You may wish to use the Understanding Models presentation on the Activity 3 webpage to do so. Introduce the U.S. Forest Service Climate Change Atlas as an online program that uses models to project potential changes to forest types, tree species, and bird species. As a class, watch the "An Introduction to Climate Change Atlas: How Does it Work?" video from the Forest Service and answer questions students have. You might revisit sections of the video to help clarify any confusion.

3. Explain to the students that they will explore two sections of the Climate Change Atlas to consider current and potential future distributions of tree and bird species habitat in the southeastern United States. Also tell the students that they will use information from the atlases to create a poster of how one type of forest might change over the next century.

4. Distribute one copy of the Atlas Guide student page to each student (or provide a link to access the student page online). Based on computer availability and student ability, decide whether students will work individually or in small groups (two or three students) and whether the Atlas Guide will be completed in class or as homework. Organize students accordingly, review instructions, and ask students to complete the student page. If students need assistance navigating the website, use the Atlas Guide presentation to show them how to use the Atlas; it has screenshots of each step. Both the Atlas Guide student page and Atlas Guide presentation refer to the Tree and Bird Atlases found at www.nrs.fs.fed.us/atlas/tree and www.nrs.fs.fed.us/atlas/bird/index.html, respectively. Caution students to stay on those pages and not to follow the link to the new Atlas.

5. After students have completed both parts of the Atlas Guide student page, explain that they will work in groups to create posters that communicate what they have learned about projected changes to climate and suitable habitat for tree and bird species in their state. Divide the class into five groups. Student groups can use any relevant responses from their completed Atlas Guide student pages, but they will likely need to revisit the websites and explore their specific topics to complete the poster. Each poster should contain important text, graphics, and pictures. Posters can be created on poster boards, butcher paper, or flip chart paper. Students can draw maps by projecting the computer models in the Atlas directly to flip chart paper. A simple reference for helping students make posters, which includes a rubric for grading, is provided in the Additional Resources section (Tips for Creating Informational Posters). Posters should contain the following information:

- ***Group 1: Projected Changes in Temperature and Precipitation.*** Using the Hadley-High and PCM-Low models, describe and compare how temperature and precipitation could change in your state.
- ***Group 2: Current Forest Types.*** Describe each forest type found in your state. Make sure to include common tree species, important forest uses and benefits, and general locations.
- ***Group 3: Projected Changes to Forest Types.*** Using the Hadley-High and PCM-Low models, describe and compare how suitable habitats for forest types in your state are projected to change. Consult with Group 1 so the information you provide does not overlap.
- ***Group 4: Tree Species.*** Describe the tree species that are identified as winners

and losers in your state. Include information about their natural history that might provide clues about why they will thrive or decline in the future climate scenarios.

- ***Group 5: Bird Species.*** Describe the bird species identified as winners and losers in your state. Do these birds require forested habitat for nesting or feeding? (Hint: look at the Life History tab for each bird species description from Cornell Lab of Ornithology, which is available at www.allaboutbirds.org.) How do you think these species might be affected by changes to their habitats?

6. Ask students to put up their posters around the room. Give students time to read each of the other groups' posters.

7. Have a class discussion about the Climate Change Atlas, different forest types in your state, and how forests may be affected by climate change.

- What characteristics make the Atlas a model?
  The Atlas uses data inputs from many sources and provides visual and numeric outputs to project potential changes to tree and bird species based on future climate conditions.

- How does the model address uncertainty?
  By using several different models to provide different projections of future changes.

- In what ways might the climate be different in 100 years?
  In some places, temperatures will be warmer, with less precipitation and drier conditions. Other locations may receive more rainfall.

- Was there a trend in how the different forest types might change?
  Many forest types will shift north and to higher latitudes.

- Which forest types seemed to be affected the most in these models?
  Answers will vary based on the model used. For both the low and high emissions models, forests in the Northeast (e.g., aspen/birch, maple/beech/birch, spruce/fir, white/red/jack pine) are projected to change significantly, with some of these forest types disappearing from the region.

- Are bird species likely to be affected by changes to forested ecosystems? How?
  Answers will vary based on the bird species assessed. Depending on how forest types are projected to change in in the state, suitable habitat for bird species might increase or decrease.

- What do you think the state's forests will look like in 100 years?
  The models in the Atlas are based on the year 2100. However, a change in suitable habitat does not mean that already established trees would immediately die. Due to the long lifespan of trees, these changes will happen over generations of trees, and it is not possible to estimate the exact timeframe.

- What might these changes mean to human communities in your state? Would anyone care if forests are different in the future?
  Forest landowners who rely on harvesting timber for income will care if the trees in their forests are not doing well. In some places, trees may be more resilient to changes than annual crops, so farmers may plant trees instead of cotton, for example.

- How did the different climate models influence the results about projected forest change? Why is this variation important to understand?
  There is inherent uncertainty associated with models, and using multiple models under different future emission scenarios allows us to see the potential range of climate projections.

- If you were a reporter writing a news story about the projections given in the atlases, which model(s) would you discuss in your story? How might your

TEACHERS SAY ...

A student commented: Making the poster was good; it helped me remember what I learned from the Atlas of Change packet.

—Environmental Science Teacher, Virginia

ADRIAN DELGADO, FRIENDS OF THE NATIONAL FORESTS AND GRASSLANDS IN TEXAS

Consider taking your students on a field trip to a forest, park, or arboretum so they can connect their new knowledge with a local ecosystem.

choice affect public understanding about climate change impacts?
Answers will vary. A news reporter who is trying to give an accurate description of the range of potential changes might discuss the differences in the models and the range of projections the models provide. If a news reporter only discusses the models that provide the least or most severe impacts, he or she may give audiences a false impression of climate change effects.

- Systems Reflection: Why are models important tools for systems thinkers?
Systems thinking skills help people to understand the behavior of complex systems. However, Earth's climate has far too many interconnected variables for anyone to keep straight without the help of a computer model. That is why models such as the ones used in this activity are so valuable. Also, models can be great tools for understanding how complex systems behave.

8. Ask students to reconsider their initial ideas about the ecological impacts of climate change (see step 1). Would they change their answers given what they learned by using the Atlas? Summarize the activity by reminding students about the usefulness of models to help us understand complex systems and the relationships among variables such as temperature, precipitation, and tree habitats. They also help us anticipate possible futures. If change is likely, what (if anything) can people do to prepare for it? If change is undesirable, what can people do to prevent it?

Modifications

It may be too challenging for students to understand the nuances among the eight different climate models, but teachers can dramatically simplify this activity by selecting one to use. Hadley-High will demonstrate the greatest change; the average shows the combination of the models with either the high or low emission scenarios.

Teachers can shorten the WebQuest by skipping the Bird Atlas (Part 2). Posters can be assembled with information from only the Tree Atlas with the first four group assignments.

Find out what scientists and forest managers in your state are doing to learn more about climate, climate change, and impacts to forest ecosystems. The U.S. Forest Service has researchers or national forest staff in all southeastern states. Visit http://www.srs.fs.usda.gov/ to find out more about what is happening in your area.

The **Systems Enrichment Exercises** for this activity allow students to work with models that make projections on a global scale.

Enrichment

Have students identify two tree species found in their neighborhoods and then use the Tree Atlas to explore both species and the potential effects of climate change on suitable habitat.

Organize a poster presentation so that others can view the students' posters. The posters could be displayed at a science night or at some other community event. Ask students to attend and stand by their posters to explain the information and answer questions.

Take a field trip to a local forest, park, or arboretum to explore native forest ecosystems.

Additional Resources

All about Birds
The Cornell Lab of Ornithology
www.allaboutbirds.org
This comprehensive website about birds and bird watching contains lots of information to aid in bird identification.

Dendrology at Virginia Tech (vTree)
John R. Seiler and John A. Peterson
http://dendro.cnre.vt.edu/dendrology/main.htm
This course website provides tree identification fact sheets on over 900 species of trees through a searchable database and map.

Systems Enrichment Exercises

MODELS DESIGNED AT THE GLOBAL SCALE ARE STILL QUITE USEFUL FOR HELPING STUDENTS (and professionals) understand changes in the climate system. In the following exercises, students can work with one or two other models that make projections on a global scale. Both exercises can help students gain greater insight into the time scales involved with international efforts to mitigate climate change impacts.

The **Understanding Climate Momentum** exercise involves the simpler of the two models that students can use. With this model, students can use a slider tool to explore several different possibilities regarding global carbon dioxide emissions, temperatures, and atmospheric carbon dioxide concentrations. This exercise can be found on the Activity 3 webpage.

The **Exploring Climate Models: C-LEARN** exercise allows students to explore how much we need to decrease carbon dioxide emissions in order to stay beneath the Nations' suggested limit of a 2 degrees Celsius (° C) increase over pre-industrial temperatures. This is equivalent to an increase of 3.6 degrees Fahrenheit (° F). Scientists suggest that a global temperature increase beyond this amount will likely cause major disruptions to the world's ecosystems, global food production, and economic development. The lesson is similar to the previous model, but the inputs are slightly more complicated. This exercise can be found on the Activity 3 webpage. Take a look at the short instructional video to learn how to use the model before beginning the exercise.

4-H Forest Resources, Florida Forest Ecology
School of Forest Resources and Conservation, University of Florida
http://www.sfrc.ufl.edu/extension/4h/trees/index.html
This website provides photographs and descriptions of 50 major trees in Florida.

A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States
Anantha Prasad, Louis Iverson, Stephen Matthews, and Matthew Peters; U.S. Forest Service
http://www.nrs.fs.fed.us/atlas/tree
This searchable database provides information on 134 common trees in the eastern United States. The key feature is the presentation of data for each species describing both the current distribution of that species and future suitable habitat based on climate change models.

A handout on the Activity 3 webpage provides helpful tips for designing informative posters.

Tips for Creating Informative Posters
School of Forest Resources and Conservation, University of Florida
https://sfcc.plt.org/section1/activity3
This handout provides helpful information and suggestions for helping students design informative posters.

Climate Modeling 101
The National Academy of Sciences
http://nas-sites.org/climatemodeling/
This website provides information and short videos on climate models and how they are constructed and validated.

How Do Climate Models Work? Koshland Science Museum
https://koshland-science-museum.org/explore-the-science/earth-lab/modeling
This easy-to-understand slideshow uses simple graphics and text to address four main topics: how climate models work, how climate models are tested, what has caused global climate change, and what are the future impacts of climate change.

Southern Forests for the Future
World Resources Institute
www.seesouthernforests.org
This program contains maps, photos, case studies, and other information to highlight key features and trends for southern forests.

Forest Service Southern Futures Project
U.S. Forest Service
http://www.srs.fs.usda.gov/futures/
This website contains the most recent papers on climate change impacts to southeastern forests.

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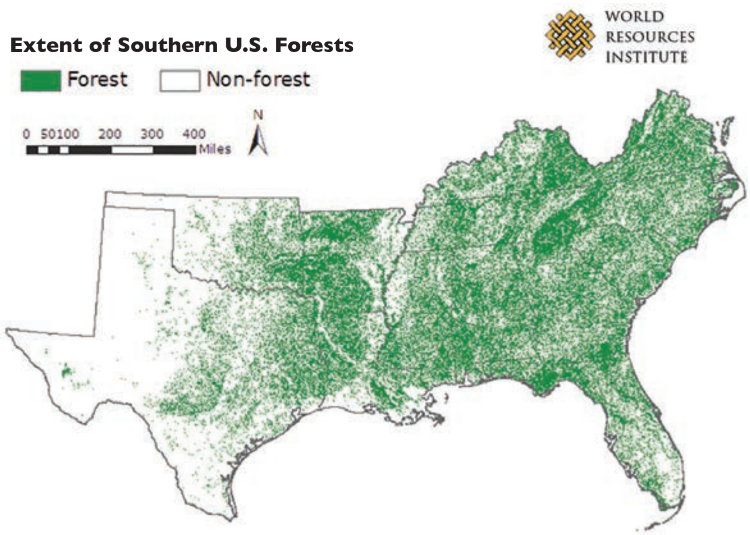
SECTION 2

Forest Management and Adaptation

Forests can be managed to thrive in a changing climate.

FORESTS COVER ABOUT 40 PERCENT OF THE LAND AREA in the southeastern United States (Miles, 2014). Several ***species*** of pine trees dominate these forests, growing in both tree ***plantations*** and ***naturally regenerated forests*** on private and public lands. Based on landowner management objectives, pine forests can be managed to provide multiple benefits, including ***timber*** products, ***nontimber forest products***, wildlife ***habitat***, water quality protection, soil stabilization, recreation, aesthetics, and land stewardship. Private land accounts for 86 percent of southeastern forests, one-third of which are owned by corporations (Butler & Wear, 2011). ***Industrial private forest landowners*** typically grow trees for timber production, creating wood products such as paper, lumber, ***biomass*** for energy, and more. As a region, the Southeast produces more wood than any single nation, accounting for 58 percent of the total U.S. industrial wood production and almost 16 percent of the world's production (Prestemon & Abt, 2002).

Extent of Southern U.S. Forests



Many of these private forests are intensively managed to produce profits from pines. Forest managers working with industrial private forest landowners (such as corporations and investment companies) select seedlings of superior genetic stock, apply fertilizer once or twice during the forest cycle to supplement the soil nutrients, manage ***understory*** competition, and watch carefully for evidence of insects and disease. Depending upon the forest and the location, trees can be ***harvested*** for pulp and paper in as few as 15 years or after 25 years, with appropriate management, for lumber.

About 40 percent of the landscape in the southeastern U.S. is forested.

Non-industrial private forest landowners include families who own land and may have cared for that property for generations. They may also grow trees for profit, though they usually invest fewer resources than the industrial landowners and it may take longer for trees to reach a marketable size. If the price of wood is low, these landowners might keep growing the trees in the hope that their value will increase in the future. They also may enjoy hunting on their property and managing the land to maximize ***conservation*** values.

The activities in this section help convey opportunities for adapting pine forest management to climate change.

Many of the managed pine forest acres of the southeastern U.S. have been regenerated using superior genetic planting stock, which is the result of tree improvement research programs that began in the 1950s. These programs have selected superior parent trees and bred them to produce ***progeny*** with better stem form, growth rates, and disease resistance. Genetic tree improvement is one ***forest management*** tool that can be combined with other ***silvicultural*** treatments to improve the overall yield, quality of products, and health of forests in this region (Zobel & Talbert, 1984).

Climate variability and uncertainty, of course, also play a role in forest management. Changes in temperature and ***precipitation*** patterns resulting from ***climate change*** will likely influence ***forest health***. While forests normally encounter disturbances, such as storms, ***wildfire***, and insect and disease outbreaks, these disturbances may become more frequent and intense in a future climate. In addition, trees and plants require specific climatic conditions to grow, and as climate changes so might the types of species that grow in certain locations.

How the forest is managed may increase its health and ***resilience*** to a changing climate, enabling the trees to withstand less rain, hotter summers, shorter winters, or more insect pests. Since trees grow for many years, forest landowners do not have the option of changing the crop they plant from year to year. In addition, forests cover many acres and are not irrigated. Forest landowners, therefore, must develop strategies to adapt practices to ***weather*** and climate over the duration of the forest management cycle.

ACTIVITY 4: The Changing Forests introduces students to the effects of changes in climate on southeastern forest ***ecosystems*** and forest management. This activity highlights current monitoring and research activities of forest scientists reported in five, two-page articles from the U.S. Forest Service's Southern Research Station magazine, *Compass*. In groups, students read one of these articles, communicate the key points to their classmates, and then summarize ways that climate change might affect southeastern forests and the role of forest management and science in responding to those changes.

ACTIVITY 5: Managing Forests for Change invites students to collectively develop a ***casual loop diagram*** (also called a systems diagram) of a forest, recalling factors that affect tree growth. Information about the priorities and opportunities that landowners use to manage their forests is provided through a short video about a private family landowner. This information is also provided in a student page. After learning about this forest, students receive management strategy cards and climate scenarios. Students use their systems diagram to explain how climate change may affect tree growth and how management options may help the forest thrive. The students' diagrams should be useful tools for showing relationships between forests, climate change impacts, and strategies people can use to manage forests. Students may wish to return to these diagrams during the summary activities in Section 5.

ACTIVITY 6: Mapping Seed Sources introduces students to ongoing research into the genetics of loblolly pine (*Pinus taeda*). Because of genetic variations between the eastern and western populations of native loblolly pines, some trees grow faster than others and some resist drought better. Students are asked to graph survival and height data from six different ***families*** of trees that share the same genetic lineage growing on three sites to determine which traits are associated with which population. Of course, if a combination of these ideal traits, such as fast growth and drought tolerance, were found in one tree, the seedlings would be well suited for wood production despite a future climate of less rainfall.

The activities in this section help convey opportunities for adapting pine forest management to climate change and for continuing to produce wood products from forests in the Southeast.

Potential Areas of Confusion

There are several topics in this section that may be sources of confusion for students, which may be based on their assumptions, prior experiences, or existing knowledge. You may be able to use questions to uncover this confusion and steer students toward the clarifications provided in the table.

Assumption or Confusion	More Adequate Conception
Nature knows best. Leaving forests alone is the best way for them to grow.	There are many advantages to wild, natural forests, and although they may not appear to be managed, many actually are. Management activities help keep forests healthy and enable people to enjoy the trails and views. In addition, if landowners wish to maximize certain components of their forests, such as wildlife habitat or timber, the forest can better meet those objectives with management. For instance, shrubs that provide berries for birds and tree seedlings with superior ***genes*** could be planted. In the face of climate change, additional management activities may be needed if natural evolution cannot accommodate the potential changes over a short period of time.
Foresters know best. Trained professionals can determine how to make any property profitable.	Professional ***foresters*** and researchers have many methods for increasing the growth of trees and making forests more profitable, as well as improving the forest for other objectives. In some areas, such as where soil nutrients are inherently limited, management may help but still not overcome severe problems. As climate varies, changes such as insect pests, endemic and exotic diseases, hurricanes, drought, and flood will make it challenging to predict successful strategies. For this reason, researchers and foresters are exploring multiple strategies to help forests resist problems and flourish despite the projected changes.
Forests are here for everyone.	The forested landscape provides many ecosystem services from which everyone benefits, such as improved air quality, ***groundwater*** recharge, and ***biodiversity***. Many forests in the Southeast are privately owned, however, and those landowners determine how to manage their forests. They may want a patch of wild nature for their family or steady income from harvesting timber. In the United States, private landowners determine what happens on their property, unless the landowners have entered their property into a land trust or conservation easement.
Genetically modified organisms are harmful.	A plant with a gene inserted using genetic engineering is known as a genetically modified organism (GMO). These plants are tested before being released to the general public. Examples of GMO crops that are commonly planted include Round-up Ready® soybeans that are herbicide resistant and Bt-corn that contains genes from a soil bacterium that are fatal to munching caterpillars. GMO methodology has not yet been applied to commercially available native pines, although it can and may eventually be a practical way to introduce resistance to diseases. Researchers currently use selection and breeding to improve genetic stock. Farmers have been selecting and breeding the best plants and domestic animals for thousands of years. Forest and horticultural geneticists use traditional plant breeding methods to select traits, fertilize flowers with selected pollen, and save the seedlings with the best form, fastest growth, and resistance to insects and disease. Most crops that provide food for millions of people and many of the trees planted in wildland and urban areas have been grown from selected varieties and seeds.

Forests can be managed for multiple objectives, including timber products, recreation, and wildlife habitat.

LARRY KORHNAK, UNIVERSITY OF FLORIDA

Key Concepts in This Section

- Southeastern pine forests are highly productive, and most are privately owned by forest industry or individuals.
- Scientists are currently working to understand how climate change might affect forests.
- Forest management strategies are used to increase tree growth and enhance forest health.
- In an uncertain climate future, ***thinned*** forests should be more resilient.
- Through selection and breeding, tree breeders and forest researchers are producing improved seedlings that could have inherited genes conveying tolerance to drought and disease or good growth and form.

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ACTIVITY

4 The Changing Forests

In small groups, students learn about research that is helping forest managers monitor and respond to climate change using new tools and management techniques.

Subjects
Agriculture, Biology, Environmental Science, Language Arts

Skills
Communication, Cooperative Learning, Critical Analysis, Leadership, Making Conclusions

Materials
Student pages, answer keys, and presentations (see Activity Webpage link below)

Time Considerations
One or two 50-minute class periods

Related Activities
Students should have an understanding of climate change (Activity 2) and the relationship between forests and climate (Activities 1 and 3). This activity can be followed with additional activities that show how forest managers can address climate change (Activities 5, 6, or 8).

Research Connection
Forest scientists focus their research in many areas, including forest health, fire ecology, genetics, and modeling.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section2/activity4

Objectives

By the end of the activity, students will be able to

- identify three ways that climate change could affect a forest ecosystem, and
- explain two monitoring or management techniques for exploring climate change and forest health.

Assessment

- Use students' answers on the student page to assess their understanding of the articles.
- Ask students to write an essay describing three changes in southeastern forests that may be due to climate change, and at least two ways that forest managers can monitor and respond to these changes.

Background

Forests are an important part of the landscape in the southeastern United States. They cover much of the land area; they are owned by public agencies, private landowners, and other entities; and they are managed for multiple objectives, including ***timber*** production, wildlife ***habitat***, recreation opportunities, and water quality protection. Given the many benefits of forests, it is important to gain a better understanding of how long-term changes to average temperature and ***precipitation*** will influence ***forest health*** and survival. For example, if temperatures are too high or too low, or if temperatures fluctuate too quickly, trees can become stressed and may die prematurely. Similarly, trees can be affected if too much precipitation results in flooding or if too little precipitation causes drought. In particular, trees growing at the edges of their ***species*** range, where they may already be stressed, could suffer the worst impacts of changes in ***climate***. These changes could cause some species of trees to die and allow for growth of other tree species that are better adapted to these different climate conditions. Over time, some trees may expand their ranges northward or to higher elevations if seedlings and young trees are able to survive in these new habitats.

Additional background information can be found in the **Section 2 Overview**.

In addition, forest health, ***structure***, and ***composition*** are influenced by disturbances, such as ***wildfire***, insect and disease outbreaks, ***invasive species***, and storms. If these disturbances become more frequent and severe, entire forest ***ecosystems*** may change. Prolonged hot, dry ***weather*** can increase wildfire risk. Drought also creates ideal conditions for the ***southern pine beetle***, and a population explosion of this insect pest can significantly impact forest health. Many invasive species can outcompete native tree species under a wider variety of temperature and moisture conditions that may result from ***climate change***. As a result of more frequent severe weather events, such as hurricanes in the Southeast, trees that are already stressed from drought are likely to be more susceptible to additional damage from high winds.


GREGORY FREY, VIRGINIA STATE UNIVERSITY

Scientists and forest managers are monitoring changes in southeastern forests and exploring how to respond to these changes with new tools and management strategies.

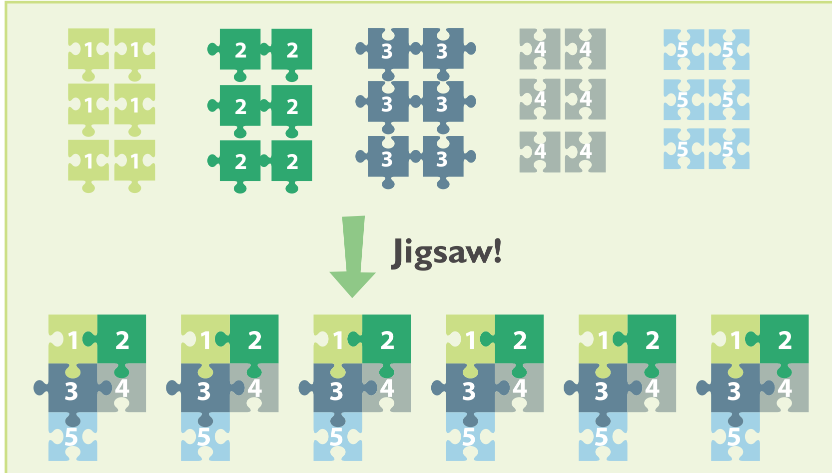
As climate conditions change, there are many ways to approach ***forest management***, but no one strategy will work for every forest. In general, it is important to create ***resilient*** forests—those that can resist and recover from disturbance—that are better able to adapt to change. Given enough time and ***genetic diversity***, many species can biologically adapt and thus survive changes in environmental conditions. However, rapid changes in the environment make it less likely that plant and animal populations will be able to change with new conditions. ***Adaptation*** to climate change includes actions taken by humans to avoid, benefit from, deal with actual, or plan for expected climate change impacts. Specific forest-related adaptation strategies include

1. instituting seed-bank programs for tree species that can tolerate drought and floods;
2. improving forest health and resilience by reducing forest stresses such as pollution, fragmentation (i.e., breaking up large continuous forests into smaller parcels by converting the landscape to other uses such as farming or subdivisions), risk of wildfire, invasive species, insects, and diseases;
3. preparing to respond to forest declines by monitoring forest health and establishing criteria for prompt intervention; and
4. planting new seed sources from trees that are adapted to growing with less water or adapted to higher temperatures.

Many scientists are currently exploring how projected climate changes might affect forests. The U.S. Forest Service employs research scientists who conduct studies, collect long-term data, and monitor forest resources on national forest lands. Results of these studies are shared with the scientific community and with forest managers, in hopes to direct management practices with the best available science-based information. In the Southeast, these U.S. Forest Service scientists work at the Southern Research Station (SRS). They are monitoring a variety of ecosystem components to better understand what is changing, whether changes can be explained by any predictable factor, and how forest managers can respond to change through adaptation strategies.

Teaching This Content

This activity uses a "jigsaw" cooperative learning technique, which allows students to more easily digest complex information and helps them practice important communication skills. Using this technique, students become responsible for part of the information the class is learning and teach other students about the most important aspects of specific topics. Before teaching others, the students work in small groups; in each group students are focused on the same topic. This time is important for students to become comfortable with the information and to share ideas with one other. The students then "jigsaw" so that new groups are formed, and each new group contains at least one member of each old group. At this point, each student has a chance to teach the new group a specific aspect of the topic. This format gives students a structured way to work in groups and provides an opportunity for practicing communication skills with a small group of peers. It enables everyone to contribute.



ORIGINAL IMAGE: ELLIOT ARONSON, WWW.JIGSAW.ORG

Getting Ready

The Activity 4 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section2/activity4).

Download the Introduction to Southeastern Forests presentation and review it to determine how much you wish to present to students. The presentation and notes are available in editable format so you can shorten or modify both as needed.

This activity uses five short articles that appeared in the June 2011 issue of *Compass Magazine* published by the U.S. Forest Service, Southern Research Station. The articles can be accessed on the Activity 4 webpage, where all five articles are provided in one PDF document.

1. "Trees in Transition" by Stephanie Worley Firley
2. "Forest Ecosystem Stress in Real Time" by Zoë Hoyle
3. "More Fuel for Fire?" by Susan Andrew
4. "CRAFTING Future Forests" by Zoë Hoyle
5. "Climate Change Invasions" by Teresa Jackson

Or, you may wish to find other articles to use for this activity. See the Additional Resources section of this activity for a few starting points to find additional articles.

In this activity, each student group begins by focusing on a different reading. Next, the groups "jigsaw" and teach each other about the key aspects of each reading.

Systems Thinking Connection

A CLASSROOM OF STUDENTS is an example of a complex ***system.*** The class roster may be relatively stable throughout the year, but the mood and behavior of the class can vary from day to day. Good teachers understand how even slight changes (e.g., a storm, an assembly) can cause noticeable changes in the students' behavior.

Forests are also complex systems in a constant state of change, as students learn in the reading, "Trees in Transition." The reason that scientists are concerned about climate change is not simply that the climate is changing, but that the pattern of changes that scientists have observed over the last several decades has never been experienced before.

Understanding these new patterns of change requires us to look for indirect connections. For example, in "More Fuel for the Fire?" students learn how severe wildfires and severe rainstorms are connected. The casual observer would likely fail to understand how these seemingly independent events could be linked, just as a novice teacher may fail to understand how an event in the morning can have an important impact on students' work during afternoon classes. Systems thinkers gain insight into the behavior of a system by focusing on the cause-effect connections that spread like a web through a complex system.

Understanding the weblike structure of cause and effect can help us avoid tunnel vision so that we can see the effects of actions that are outside of our narrow focus. For example, in "CRAFTING Future Forests" students learn how forest managers no longer focus on a single value or variable. Instead, they learn to take a broader view regarding the impacts of their decisions. Expanding the way we think to include the most appropriate systems boundaries is an important systems thinking skill.

TEACHERS SAY ...

I loved the lesson and the jigsaw with articles. Students were willing to share the information they learned and were able to answer questions. I was thrilled at their efforts.

—Earth and Environmental Science Teacher, North Carolina

Make copies of the Changing Forests student pages (each student should receive one student page to correspond with his or her *Compass* article).

If you have more than one class period for this exercise, students can read the article in their groups. If you have only one period, ask students to read the articles for homework and to be prepared to discuss the information when they come to class. You can assign the questions as homework as well or save them for the first group activity.

Doing the Activity

1. Ask students to imagine a forest. What types of trees do they see in their forests? Where are their forests located? Did any students think about a forest close to home? Explain that forests are an important part of the landscape in the southeastern United States and provide a short introduction to forests and forest management in the region. You may want to use the Introduction to Southeastern Forests presentation on the Activity 4 webpage. You can also use information provided by your state forestry agency's website to share locally relevant information.

2. Ask students to imagine their forests again, but now have them consider how their forests will respond to future changes in climate. What might they see change in their forests as a result of anticipated changes in temperature and precipitation patterns? If they were scientists, what sort of observations or data would they collect to study these changes? Explain to students that the U.S. Forest Service employs scientists who conduct research on national forest lands, and these scientists are investigating strategies to monitor and detect change and adaptation strategies that forest managers can implement to respond to those changes.

3. If you didn't previously complete Activity 1 with your students, consider taking 15 minutes to complete Part B of the activity. Part B provides a worksheet for students to complete while watching a video from the U.S. Forest Service, which introduces climate change science, impacts on forest ecosystems, and the Forest Service response to climate change (video is available on the Activity 1 webpage).

4. Divide the class into five equal topic groups. Each topic group should be assigned to read one of the five *Compass* articles. These articles contain information about climate change research being conducted by U.S. Forest Service scientists. Give each student in each group a copy of the article and the associated Changing Forests student page. Alternatively, the articles can be read online.

5. Ask students to read the articles and complete the Changing Forests student page as a group or as homework. Answer keys are available on the Activity 4 webpage. The group task is to make sure each student is familiar enough with the information to be able to teach it to other students in 3 minutes. Give students in the topic groups at least 15 minutes to discuss and answer the questions based on the articles. Allow more time if necessary.

6. Ask students in each topic group to count off so that each person has a different number. The students should then reform new groups according to their numbers. Each new group should have at least one person from each previous topic group.

7. In the new groups, ask one student in each group to be a timekeeper. Each student should take 3 minutes to explain his or her article to the other students. When the student is done, the other students may ask questions.

8. When everyone understands all five articles (about 20 minutes), ask students to discuss the following questions.

- What common themes do the five readings have?
Answers may include: climate changes are causing changes in forest ecosystems; climate changes are causing a variety of different forest stresses; new models are being developed to predict climate changes and the impacts of these changes; scientists are studying ways to understand the effects of climate change on forest ecosystems and to develop ways managers can help ecosystems adapt to these changes.

- What are some indicators that changes have occurred during the past 30 years?
Answers may include: warmer, drier conditions have occurred; extreme weather events happen more often; species that thrive in warmer climates are able to expand their ranges.

- What are some impacts from climate change that southeastern forests might face in the future?
Answers may include: changes in the genetic makeup of forest tree species, changes in ranges of forest tree species, increased drought, more frequent and more intense forest fires due to greater fuel loads, stronger and more frequent tropical storms, and greater opportunities for invasive species, which could jeopardize the health of native forest species.

- What strategies can forest managers and scientists use to respond to climate changes and to improve forest health?
Answers may include: prescribed burnings, conserving genetic variation, using models to predict changes, and using models to determine areas of forest stress.

- From the readings, what future career opportunities can you identify?
Answers may include: forest ecologist, land manager, and research scientist in various related fields, including plant genetics, hydrology, dendrology, and agricultural technology.

- Why are adaptation strategies important for forest ecosystem health?
Adaptation strategies are important to help humans and forest ecosystems adjust to climate change already occurring. Human assistance is needed because many of these changes might happen too quickly for the crops we depend on to naturally adapt.

- Systems Reflection: How are severe storms and severe wildfires related to climate change?
In some cases, severe storms can create more fuel by blowing down large trees. More fuel may mean more intense wildfires. However, as the article explains, that is not always the case. The authors also note that these large fallen trees may keep enough moisture through the dry season to help decrease fire risk.

- Systems Reflection: In what way has human development around forests made forest management decisions more complex?
When forest managers make decisions, they must keep in mind the needs of the people living near those forests. In some cases, managing for the most resilient forest possible might create other problems for local residents. The CRAFT resource discussed in the article is designed to help forest managers recognize how their decisions affect other systems and people as they ripple out through the web of social and ecological connections.

- Systems Reflection: What variables should be considered as part of the forest system to best understand forest changes caused by climate?
The important variables will vary somewhat, depending on the forest. However, precipitation and available water, nutrient levels and soil health, low- and high-intensity fires, and temperature are all likely to impact the health and growth of any forest.

9. Summarize this activity by asking students to reflect on the importance of conducting research on forested lands.

TEACHERS SAY ...

After discussing the questions with my students from the various articles, they seemed to really understand a whole lot more about climate change.

—Earth Science Teacher, Florida

TEACHERS SAY ...

I will be doing this activity again because I think the articles were good and the discussion questions were appropriate for my lesson plan.

—AP Environmental Science Teacher, Florida

Why is it valuable to collect data over long time periods? How do they think research projects like the ones described in the articles benefit society? Remind students that national forests are public treasures that provide wildlife habitat, clean water and air, places for people to recreate, timber products, and natural scenery. U.S. Forest Service researchers are exploring climate change and forests to better understand how to care for these areas through appropriate management practices.

Modifications

Depending on your students' needs and abilities, you may want to provide students with a short overview of each article before they break up into their small groups.

You can reduce the number of articles so that you can more easily help each group as they complete the activity. You can also reduce the number of questions on the student pages using the file provided on the Activity 4 webpage.

You may choose to forego the jigsaw approach, read the articles together, and complete the student pages together. Keeping the class together, rather than splitting into groups, may be helpful if your students become easily distracted or find it hard to stay on task. If you choose to read fewer articles, we suggest you pick those that cover both the impacts of climate change and how scientists are modeling and monitoring those changes in the forest: "Climate Change Invasions," "Forest Ecosystem Stress in Real Time," or "Trees in Transition."

Enrichment

Partner with a local natural resource expert for a class field trip that investigates how climate change might affect schoolyard trees and wildlife, wetland habitats, or nearby forests.

Suggest that students interested in science read the scientific articles linked to each of these *Compass* articles by searching for the authors name on TreeSearch (www.treesearch.fs.fed.us). They can also find additional articles written by other authors.

Have students read the introduction of "Science at Your Fingers" to learn about a U.S. web-based tool called TACCIMO (Template for Assessing Climate Change Impacts and Management Options). TACCIMO is intended for use by land managers and provides the most current climate change projections and research in an effort to link science to forest management and planning. The "Science at Your Fingers" article is available at http://www.forestthreats.org/products/fact-sheets/EFETAC_TACCIMO_2013_printerfriendly.pdf). Students can then explore TACCIMO and develop management ideas to address negative impacts of climate change on forest ecosystem (http://www.taccimo.sgcp.ncsu.edu).

Invite a forest researcher to class to talk about the types of research he or she conducts and how climate change might affect forests.

Advanced students can explore a web-based tool called WaSSI (Water Supply Stress Index Ecosystem Services Model, http://www.forestthreats.org/research/tools/WaSSI) to learn how changes in precipitation and temperature may affect water resources and forest ecosystems at the regional watershed level.

Additional Resources

Climate Change Impacts and Adapting to Change
U.S. Environmental Protection Agency (EPA)
www.epa.gov/climatechange/impacts-adaptation/index.html
This section of the U.S. EPA climate change website provides information about the impacts of climate change and adaptation efforts by region and by sectors, such as forests, agriculture, and ecosystems.

CompassLive Blog
U.S. Forest Service, Southern Research Station
http://www.srs.fs.usda.gov/compass/
A blog designed to share the latest information on southeastern forests from the U.S. Forest Service.

Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S.
U.S. Forest Service, Pacific Northwest Research Station
http://www.treesearch.fs.fed.us/pubs/42610
This assessment analyzes current and future conditions of forests with specific interest to climate change impact.

Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers
Chris Swanston and Maria Janowiak, Editors; 2012
http://www.nrs.fs.fed.us/pubs/40543
This US Forest Service General Technical Report provides resources, including a workbook, to help forest managers incorporate climate change considerations into management and devise adaptation tactics.

Neil Sampson Says Climate Change Speeding Flux of Forest Ecosystems
EarthSky
http://earthsky.org/earth/climate-change-speeding-flux-of-forest-ecosystems
During this 90-second podcast, scientist Neil Sampson describes how forests may be affected by climate change.

State Climatologist Interview with NC People
State Climate Office of North Carolina
http://video.pbs.org/video/2134881398/?starttime=671000
During this video, the North Carolina State Climatologist, Ryan Boyles, Ph.D., explains how climate change can impact southeastern forests.

Southern Forest Futures Project: Summary Report
U.S. Forest Service, Southern Research Station
http://www.srs.fs.usda.gov/pubs/42526
This summary includes results from the Southern Forest Futures Project technical report and provides a set of key findings and implications.

State Resources, Southern Regional Extension Forestry
Southern Regional Extension Forestry
http://sref.info/resources/state-resources
From this website, you can click on any state in the Southeast and find a listing of the state's forestry agency, university or college with a forestry school, and Extension programs. These state-specific resources provide localized information about forest research and resources. You can also check out the Current Projects page (http://sref.info/projects/current) to learn about regional forestry projects in the Southeast.

U.S. Forest Service, Research and Development
U.S. Forest Service
http://www.fs.fed.us/research/
The U.S. Forest Service has research stations located regionally throughout the country. Their websites are a good starting point for identifying current forest research and can be accessed, along with other news and highlighted research, through the Research and Development webpage.

In the **PINEMAP Focus on Research** video on the Activity 4 webpage, you can learn about WaSSI model from a U.S. Forest service scientist who helped develop the model.

Changing Forests: Trees in Transition

NAME DATE

1. The introduction states that the only constant is change. If forests always change, what's the problem?

2. How might tree populations respond to changes in the climate?

3. What is the ForeCASTS project? How are ForeCASTS maps useful?

4. Why is it important to conserve genetic variation?

Changing Forests: Forest Ecosystem Stress in Real Time

NAME DATE

1. What is RAFES and what is it intended to do?

2. What is the problem with current ecosystem assessment, and why is the new approach more effective?

3. What important forest stressor is being researched for this project? Why is this stressor important?

4. How do you think drought increases forests' susceptibility to pests, disease, and wildfire?

Changing Forests: More Fuel for Fire?

NAME DATE

1. What is the KBDI? What does a high KBDI mean?

2. In which geographic area is the increase in the length of fire season expected to be the greatest?

3. Describe the changes in fuel loads predictions. Which areas will have a decline? Which areas will have an increase?

4. What is a management option to reduce wildfire risk?

Changing Forests: CRAFTING Future Forests

NAME DATE

1. What is the Forest Service National Roadmap for Responding to Climate Change?

2. Why is there a strong interest in restoring longleaf pine forests in the Southeast?

3. What challenges do forest restoration specialists face?

4. What is CRAFT? How does CRAFT help managers and stakeholders make decisions for the future?

Changing Forests: Climate Change Invasions

NAME DATE

1. How will invasive plants likely be affected by climate change?

2. What types of tools are EFETAC researchers using to assess how climate change will affect the distribution of plant species?

3. What is required to understand how invasive species affect native habitats and species?

4. What is the goal of the EFETAC research?

ACTIVITY

5

Managing Forests for Change

This activity allows students to explore the connections between forests, climate change impacts, and management strategies for creating resilient forests. Students draw these connections in a systems diagram, a tool that helps them see the system.

Subjects
Agriculture, Biology, Environmental Science

Skills
Determining Cause and Effect, Diagramming Systems, Identifying Relationships and Patterns, Predicting

Materials
Student pages, answer keys, and presentations (see Activity Webpage link below). Optional: colored pens or markers, large pieces of paper, yarn, tape

Time Considerations
Two to three 50-minute periods

Related Activities
Students should have an understanding of climate change (Activity 2) and the relationship between forests and climate (Activities 1 and 3). This activity can be followed with additional activities that show how forest managers can address climate change (Activities 4, 6, or 8).

Research Connection
Forestry research in the Southeast explores strategies that can create profit from resilient forest plantations. The management strategies included in this activity are based on research findings from comparison plots across the Southeast. Family landowners may have additional management objectives for their property, such as wildlife habitat and a legacy for their family.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section2/activity5

Objectives

By the end of this activity, students will be able to

- explain how forest managers can manage forest plantations to thrive in a changing climate,
- create a systems diagram to explain forest health and productivity, and
- predict how changes in climatic conditions and management strategies might affect forest health and productivity.

Assessment

- Use students' answers on the student page to assess their understanding of the articles.
- Ask students to write an essay describing three changes in southeastern forests that may be due to climate change, and at least two ways that forest managers can monitor and respond to these changes.

Background

Good ***forest management*** practices are important to ensure the health and stability of forests. To achieve a landowner's objectives, ***foresters*** develop management plans that detail the practices and activities they will apply to the forested land. These activities may include replanting practices, ***species selection***, tree ***harvesting*** and ***thinning*** schedules, fertilizer applications, steps to enhance wildlife ***habitat*** or ***biodiversity***, actions to protect water quality, strategies to protect trees from insect pests and disease, and ***vegetation*** management to reduce ***wildfire*** risk and competition with the trees. Most of the forests in the Southeast are privately owned and many are managed for ***timber*** or pulp production.

The management activities described in this activity are based on techniques that are commonly used by forest landowners who wish to harvest trees for income. Most of these strategies also can be used in ***naturally regenerated forests*** that are managed for biological diversity and recreation.

Forests as a System

When thinking about the forest as a ***system***, it is easy to see why management

Additional background information can be found in the **Section 2 Overview** and in **Activity 4**.

strategies might be needed to maximize the landowner's objectives. This activity begins by helping students generate a systems diagram of a forest. Specifically, students create a ***causal loop diagram***, which is a tool to visualize and better understand the cause-effect relationships between parts of a system. The presentation, Building a Forest Systems Diagram, is available on the activity webpage to help you teach this important skill. The teacher notes in the presentation include a script that will guide you and your students through this process. In this diagram, tree growth is the landowner's objective, so that is at the top. The diagram includes several variables the landowner can manage to affect tree growth.

Systems diagrams are useful for picturing how different aspects of a system, such as a forest, are connected through cause-effect relationships. John Muir famously said, "When we try to pick out anything by itself, we find it hitched to

LARRY KORHNAK, UNIVERSITY OF FLORIDA

Many pine forests in Southeast, such as this loblolly pine plantation, are managed to produce wood products such as paper and timber.

everything else in the Universe." Of course, he didn't necessarily mean that everything is *directly* linked to everything else. He was referring the web of relationships in which things are connected indirectly to each other. These indirect connections matter a great deal in the behavior of an ***ecosystem***.

In this activity, students learn how to create and use a simple systems diagram to track the cause-effect relationships in a forest and predict how that system would likely change in the face of environmental changes and management measures. They learn how changes can ripple through a system through indirect connections in the web of cause-effect relationships. When decisions are made without considering the web of relationships, we may fail to anticipate the undesirable side effects of our actions. A forest system can include many more variables and relationships than we have used here. We have included the key elements for this activity.

In addition, students are introduced to the concept of feedback loops. In teaching, we use feedback to direct student behavior. If a student behaves in a desirable way (completing homework), we reward that behavior in hopes of fostering continued efforts in that direction. Conversely, if a student behaves in an undesirable way (skipping class), we take measures to change that behavior.

We can see a similar pattern in complex systems when two or more parts of a system are connected to each other so that a change in one variable ripples through the system and comes back to affect that variable. There are two different types of feedback loops. ***Reinforcing feedback loops*** (also called positive feedback loops) can turn small changes into larger changes. Fads are an example of a reinforcing feedback loop. When a television show or a product becomes popular with a few people, other people hear about it and become interested. As this larger group experiences the show or product, even more people hear about it, so it becomes even more popular. As more people watch the show and talk about it, more people watch the show. This is what happens when a YouTube video goes viral (figure 1). A reinforcing or positive feedback loop (called positive even when the outcome is not good) that causes rapid change in an undesirable direction is referred to as a vicious cycle. For example, in the vicious cycle of poverty and environmental degradation, an increase in one causes an increase in the other, which loops back and amplifies the first change. This cycle continues until the situation spirals out of control. Of course, this same feedback loop could reinforce continuing *decreases* in poverty and environmental degradation. Part of being a systems thinker is looking for ways to use reinforcing feedback loops to create desirable change.

Systems also have ***balancing feedback loops*** (also called negative feedback loops)—the most common example is the thermostat in your refrigerator. If the temperature in the fridge gets too warm, the motor comes on to cool things off. Once the fridge has cooled to the desired temperature, the motor turns off. In other words, any major change in the system evokes a response to reverse that change. Populations are often balanced by constraints in food supply. In our forest systems diagram, there is an example of a balancing (or negative) feedback loop as tree growth affects competition for water and nutrients. The terminology positive and negative does not refer to beneficial or detrimental outcomes, but to the way that positive feedback reinforces or compounds an action and to the way that negative feedback balances or maintains a system.

In this systems diagramming activity, in addition to placing the arrows and understanding the relationships, students will label the arrows to indicate how a change in one variable affects the variable on the receiving end of the arrow. The presentation, Building a Forest Systems Diagram, provides examples and explanation for helping students add an S when the two variables change in the SAME direction and an O when the change is in OPPOSITE direction. (AP Environmental Science teachers may prefer to use a + for the same direction and a - for opposite. An odd number of minus signs in a loop will indicate a negative feedback loop.)

Climate Change Impacts

In many areas of the Southeast, it is increasingly important for forest managers to consider ***climate change*** when choosing management strategies, as variations in ***climate*** will likely affect pine forest ***productivity*** and ***forest health*** over the life cycle of the trees. The importance of these management activities can be seen in the forest system diagram too. Although temperature changes in the Southeast are not expected to be as large as in the North, much of the region may experience a rise in average temperature, which can alter the growing season length, fire patterns, and ***plant and animal*** migration. ***Precipitation*** patterns may also change. Climate ***models*** suggest that some areas will receive less rain and others will receive more. Much of the additional precipitation may not fall during the growing season, however, or may arrive in unusually strong storm events. When large storms produce torrential rain, much of the water runs into surface drainage areas rather than filtering into the ground. Impacts on southeastern pine forests will vary. For those places that experience warm and moist conditions, growing seasons could become longer, which could increase tree productivity. Alternatively, prolonged droughts could stress trees, decrease productivity, and impact tree survival. For a good introduction to visualizations of climate models, see **Activity 3: Atlas of Change.**

Increased atmospheric carbon dioxide (a cause of climate change rather than an impact) may also influence tree growth. Most experiments show that trees initially grow faster when the atmosphere has higher levels of carbon dioxide. At some point, this increase slows or disappears as growth becomes limited by other factors such as reduced soil nutrients or water availability.

Additional factors influenced by climate change, such as soil moisture, wildfire, insects, and diseases, also impact pine forests. Changes in precipitation and temperature influence ***evaporation*** and ***groundwater*** levels, both of which affect the amount of water stored in soils and trees. Longer periods of hot, dry

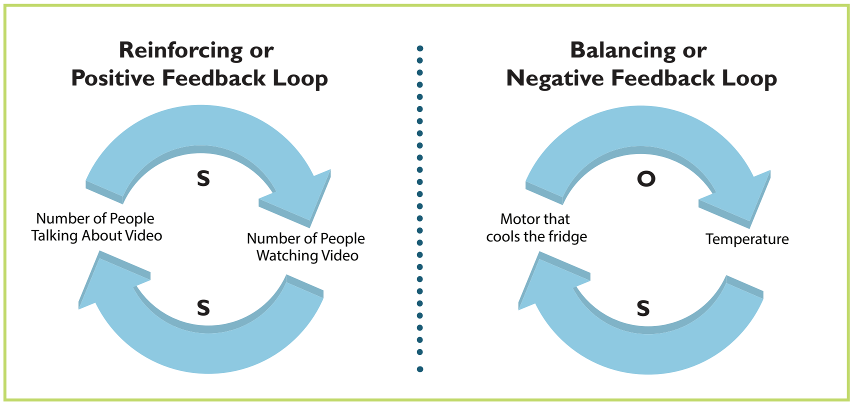


Figure 1. Systems can have reinforcing (or positive) feedback loops, where the cause-effect sequence tends to amplify change (left). Systems can also have balancing (or negative) feedback loops, where the cause-effect sequence tends to resist change (right).

DAVID GODWIN, SOUTHERN FIRE EXCHANGE

Prescribed fire is used in southeastern forests to reduce wildfire risk and to maintain or restore fire-dependent ecosystems.

conditions could increase the frequency and severity of wildfires. Increased temperature across the region and a greater increase in hurricanes could also enable forest insects, such as bark beetles, to expand their range. When the population of these insects peaks, they can be enormously destructive, especially when trees are stressed by drought, overstocking, or extreme ***weather*** events. ***Invasive species*** from tropical areas are also likely to increase their ranges. Climate conditions, tree growth, and forest stressors are interrelated. For example, reduced summer precipitation and increased temperature during the growing season lead to increased moisture stress, as less water is available for the trees. This in turn could reduce growth rates and increase the risk of disturbance by fire, insects, and disease. Conversely, increased precipitation could decrease competition for water and increase tree growth. Of course, if precipitation remained high, flooding could occur, which would reduce tree growth. The Suggested Solution Diagrams presentation found online shows how to discuss these possibilities in the context of the systems diagrams.

Forest Management

As climate conditions change, there are many ways to approach forest management, but no one strategy will work for every forest. In general, it will be important to create ***resilient*** forests—those that can resist and recover from disturbance—that are better able to adapt to change. Given enough time and ***genetic diversity***, many species can biologically adapt and thus survive changes in environmental conditions. However, rapid changes in the environment make it less likely that plant and animal populations will be able to change to meet the new conditions. ***Adaptation*** to climate change includes actions taken by humans to avoid, benefit from, deal with actual, or plan for expected climate change impacts. These include some management options that may enhance the ability of forests to adapt to climate change such as the following:

- **Thin crowded forests:** As trees grow, forests can become increasingly crowded and competition between trees can become intense. While overcrowding often happens in naturally regenerated forests, tree seedlings in a ***plantation*** forest are usually planted at a high density to ensure that trees grow straight with fewer branches. Once the trees reach a certain size, they begin competing for resources such as light, water, and nutrients. When these factors are limited, the trees can become stressed, making them more susceptible to disease and insect attack. In addition, overcrowded forests are more susceptible to mortality from wildfire. Removing some trees from the forest reduces tree stress and enhances the growth of the remaining trees. It also decreases the risk of wildfire, insect attack, and disease. Even though removing trees from a forest sounds like it will reduce income to the landowner, in most cases the remaining trees will be larger and will sell for more money than the smaller trees from an unthinned forest.
- **Promote genetic diversity:** Forests with some variation in genetic diversity (different species or different ***families*** of a single species) may be better able to withstand uncertain environmental changes than forests with little genetic diversity because they might be more resilient. Species and families differ in their ability to grow under different climate conditions. For example, longleaf

Systems Thinking Connection

THROUGH THIS ACTIVITY, students see that cause-effect relationships in a forest look something like a web. This weblike structure is typical in complex systems as are the feedback loops described in the background section of this activity. Feedback loops play a large role in the stability (and instability) of complex systems. Indeed, the enormous web of cause-effect relationships and the prevalence of numerous feedback loops are the major reasons why making precise predictions about climate behavior is so difficult. Two additional Systems Enrichment Exercises help students practice making systems diagrams.

(*Pinus palustris*), sand (*P. clausa*), and shortleaf (*P. echinata*) pines are more drought tolerant than loblolly (*P. taeda*) and slash (*P. elliottii*). Even within a species, some trees are better able to tolerate certain environments than others. Planting a variety of improved genotypes may enable some trees to thrive even in great uncertainty about climatic conditions. See **Activity 6: Mapping Seed Sources** for more information on genetic diversity within a species.

- **Use prescribed fire:** Many southeastern forest ecosystems are adapted to the periodic, low-intensity fires that historically have occurred naturally. Without periodic fire in the ecosystem, the forest ***understory*** can become filled with fast-growing vegetation and dead organic matter. Over time, the absence of fire changes the makeup of an ecosystem and creates hazardous fuel loads, so that when a fire does occur, it is more intense and damaging. To reduce wildfire risk and to maintain or restore fire-dependent ecosystems, trained professionals plan and conduct ***prescribed fires*** in natural areas under appropriate weather and safety conditions.
- **Using improved fertilizers:** Many pine plantations grow on nutrient-poor sandy soil. If forest landowners are able to supplement soil nutrients with fertilizer once or twice during the life span of their trees (roughly every 8–10 years), the trees grow faster and sequester more carbon. Maintaining vigorous growth of the trees can make them less susceptible to insect attacks and drought. Researchers are developing specialized fertilizer that is taken up by trees more efficiently, allowing foresters to apply less fertilizer to get similar increases in growth.

Teaching This Content

This activity engages students in systems thinking. If you have not been using the Systems Enrichment Exercises, you may wish to use the **Dynamic Systems Dance** exercise on the Activity 1 webpage to help explain the concept of a system. Being able to draw a system by identifying components and their relationships may be a new skill, and it is a helpful step to understanding and thinking about systems. Pilot testers who were unfamiliar with this concept found that reviewing the slide presentations and slowly explaining the relationships helped their students better draw diagrams and understand them. The Suggested Solution Diagrams presentation is available if you wish to work through one example with students.

Some students may think that forests will die because of climate change, particularly if a recent drought or wildfire has occurred nearby. Such severe and direct impacts are not typical, though they might occur in some places. It is more likely that trees will be stressed and vulnerable during one season. During the period of drought, for instance, trees may not grow much and may be susceptible to other stressors, but they are not likely to die in one year. In this way forests are more resilient than corn and other crops. However, long term drought and other stressors have the ability to weaken trees to the point where beetles or disease could kill them.

TEACHERS SAY ...

My students (and I) were unfamiliar with the modeling activity, but, after slow, careful explanation, they were able to understand and process the information.

—AP Environmental Science Teacher, Florida

TEACHERS SAY ...

I had the most response and most active learning in my classroom with this two-day activity. The conversations in the groups the second day when we added the management squares to the forest systems model were engaging and lively. The discussions about climate change for the forest landowner went well.

—Biology Teacher, Florida

Getting Ready

The Activity 5 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/ section2/activity5).

A background in local forest management practices will help students with this exercise. You can use the Introduction to Southeastern Forests presentation on the Activity 5 webpage to introduce students to this topic. In addition to the background and resources provided here, a guest speaker from your state forest or Extension agency could help explain the management terms and answer questions about nearby forests.

Download the Building a Forest Systems Diagram presentation from the Activity 5 webpage and review it to determine how you wish to present the information to students. Even if students have experience making causal loop diagrams, this activity will be more successful if all students use the same framework for understanding the system's variables and relationship, which is the system they will create using the Forest Diagram student page.

Make copies of the Forest Diagram student page so students can add the arrows as you explain the system. It is possible, of course, to design many forest systems diagrams with many relationships; this abbreviated version helps students consider climate impacts and management options. The video on the activity webpage provides a brief explanation of systems by Dr. Richard Plate.

Decide whether you will have students watch the Private Family Landowner video or read the student page, which has been adapted from the video. Make copies if necessary. Make a copy of the Management Cards for each group.

Review the Suggested Solution Diagrams presentation to decide which climate scenarios to give students and how to discuss their responses. The presentation provides potential answers that students may generate as they add variables and relationships to their diagrams in Part B of the activity. Then copy and cut apart the Climate Scenario Cards you chose and give one or two to each group.

Doing the Activity

Part A: Visualizing the Forest Connections

1. Begin the activity by asking students to describe nearby forests that are harvested for wood products. These are likely privately owned forests (either by individuals or corporations) and in many areas of the Southeast are probably pine plantations. In this activity, your students will provide advice to Doug Moore, the landowner featured in the video and student page, who is wondering how to best manage his forest for future climate conditions. Introduce Mr. Moore and his forest with either the video or student page to help students visualize his forest.

2. Explain that a systems diagram of a forest helps people see the connections and relationships in a forest ecosystem, and through those relationships, predict how changes could affect the forest. This is an important strategy for providing Mr. Moore with good advice. Students need to see the whole forest (and its ecosystem) not just the trees! Distribute the Forest Systems Diagram student page and ask students to follow along with your presentation of Building a Forest Systems Diagram by adding the arrows and S for SAME or O for OPPOSITE to designate the relationships between variables that you introduce. You may wish to demonstrate the first few relationships and then call on students to explain the next relationship or set of relationships (both options are available in the presentation). This may be helpful in conveying the relationships: "When forest density is *increased*, competition is *increased*, and nutrient availability is *decreased* (O), which *increases* stress (O) and *reduces* tree growth (O). If forest density is *reduced*, competition is less severe, so trees obtain more nutrients

(O), are less stressed (O), and grow more." If students use the diagram with one initial condition (forest density is increasing) to insert the symbols, they can check their symbols with the opposite condition (forest density is decreasing). The symbols should stay the same. Only some variables and connections are illustrated to emphasize the relationships that play particularly important roles in the context of this exercise. A complete diagram of this system is included in the presentation.

3. Check that the class understands how to use the diagram to track cause-effect relationships by asking them to draw an additional arrow to show how more frequent wildfires might affect understory vegetation *(An O feedback arrow between High-intensity wildfire and Understory fuel load will make this a balancing or negative feedback loop).*

Part B: Making Management Decisions

1. During the second part of the exercise, students use their basic forest systems diagram to decide how Mr. Moore could manage his forest in a future with changing climatic conditions.

2. Divide the class into small groups and give each group one or two climate scenario cards and the page of management cards. Ask them to draw, on their forest systems diagram, the additional variables listed on the cards to show how climate change might affect this forest. Then ask them to select one or two management activities and show on the diagram how these strategies could reduce those potential climate impacts. It might help for students to use different colored pens or markers when adding these variables and arrows. The Suggested Solution Diagrams presentation and teacher notes provide ideas about how to explain this task.

3. Give the groups 15 minutes to add the climate and appropriate management variables, draw the changes on their Forest Systems Diagram student page, and discuss the following questions in the group:

- How might climate change affect this forest?
  Each climate card specifies one possible change and suggests new variables that should be added.
- Which management strategies might become important to enable the forest to thrive with this possible climate change?
  Several management strategies may be helpful in response to each potential climate change (see Suggested Solution Diagrams presentation).

4. Ask each group to present one diagram, explaining the group's ideas about how the forest might be affected by change and the management strategies they chose to address these changes. The Suggested Solution Diagrams presentation includes some sample results for these scenarios; others are possible.

5. After all groups have presented, discuss the following questions as a class:

- What are some general trends for how climate change might affect forests?
  Small changes in temperature and precipitation can improve growing conditions; large changes may add stress to trees by increasing the possibility of disease and severe fires.
- Which management practices could help landowners increase forest resilience?
  Thinning forests can help keep trees from becoming stressed by competition or disease. Planting superior seedlings can improve tree growth. Maintaining genetic diversity by planting multiple families of improved seedlings can help some trees survive a variety of conditions.
- What is an example of an indirect relationship on your diagram?
  Drought indirectly affects tree growth. Rather than having an arrow that goes directly from drought to tree growth, notice that the arrow goes from drought to water availability, from water availability to tree stress, and finally from tree stress to tree growth.

TEACHERS SAY ...

The assessment was very helpful. I like hearing students explain the concepts to each other.

—Sixth Grade Science Teacher, Kentucky

TEACHERS SAY …

I needed to work more closely with the students and we did the model together. I enlarged and cut out each of the components and laminated the cards so students could place them on a larger piece of paper and draw the arrows as we completed the model together.

— *Ecology Teacher, Virginia*

- Your diagram helps you see the relationships in a forest at one particular time. Pretend it is ten years later and the trees are all larger. Where on your diagram would you see feedback loops indicating how the larger trees affect some of these variables?
  Water and nutrient availability will decrease.
- Under which climate scenarios might wildfire occur? What management strategies could reduce the risk of wildfire?
  Wildfire may be more likely in climate scenarios that involve drought. Both prescribed fire (if done with care) and thinning could reduce this risk.
- If increased atmospheric carbon increases tree growth, which variables on your diagram might limit tree growth? Could a forest landowner change those limiting variables?
  Water and nutrients will likely limit tree growth; nutrients could be added through fertilizer, but forest landowners do not have the capacity to irrigate their forests like a farmer might. Thinning should make more water available to remaining trees.

6. Systems Reflection: Summarize the activity by reminding students that a systems diagram is one tool for visualizing a complex system and predicting how the system might respond to change. As your students become more familiar with system modeling, they may see systems in lots of places, such as the school bus routes and school schedule, baggage handling in an airport, or dinner preparations at home. Similar to these other systems, forests will be subjected to many possible conditions and variations over time. Putting the system on paper helps to simplify it and allows students to see how the relationships can be used to attain the intended objectives.

Modifications

Teachers can simplify this activity by keeping the class together and making a large systems diagram on the chalkboard or bulletin board rather than dividing into small groups and using individual student pages. Colored yarn can be used to designate relationships.

Grouping sets of variables together may make it easier to explain the diagram.

Using only a few of the climate scenarios and working together to alter the large diagram may be a useful strategy for Part B.

Students will know from common sense that if there is less rain, trees will not grow as much, so you can ask them to check their diagrams to make sure that is conveyed. Then select a less obvious change and ask student what the diagram predicts could happen.

Review any unfamiliar forestry terms prior to beginning the activity.

Enrichment

If your students already know something about forest management, you may wish to distribute the forest diagram variables cards and ask groups to create their own diagrams (without using the Forest Diagram student page).

Ask your students to make a forest system diagram for a public forest. A description of a public land agency forest is available on the Activity 5 webpage in the optional Public Land Agency student page. This information can be supplemented with information from your state's forest agency. Instead of using tree growth as the ultimate goal for forest management, students may use forest health or biodiversity for the key variable at the top of their diagram. Students can also work through more climate scenarios. Information from Activity 3 can be used to develop climate scenarios for your region.

After working through the various scenarios in this exercise, instructors may want to make a more thorough systems diagram using information from the background section or from other exercises in this module. While doing this can be a useful exercise, there is a strong possibility that the final product will be a very complicated diagram, containing many variables and a tangle of connections. While the predictive capability of such a map is limited, it may help students to understand that there are truly a multitude of connections in a forest ecosystem. In light of such connections, it is not surprising how even seemingly insignificant management decisions can have broad effects that ripple through the system. Alternatively, instructors may want to encourage students to focus on a limited set of variables in order to keep the systems diagrams from becoming overwhelming.

Additional Resources

America's Longleaf
America's Longleaf Restoration Initiative
http://americaslongleaf.org
This website describes an initiative to restore and conserve longleaf pine ecosystems. The site also includes lots of publications, photos, and maps with information on longleaf pine ecosystems.

Forest Encyclopedia Network
U.S. Forest Service and Southern Regional Extension Forestry Office
www.forestencyclopedia.net
This website has several encyclopedias that provide scientific knowledge and tools related to forest ecosystems and management.

Forestry Instructional Film - It's Time to Thin!
School of Forest Resources and Conservation, University of Florida
http://www.youtube.com/watch?v=dBxGxeAagtE
This short video explains the forestry practice of thinning to improve forest health, resilience, and profits on timberland.

If you wish to explore additional strategies for explaining systems, check the Sustainable Tomorrow Teacher's Guide or the Systems Thinking in Action website.

Systems Enrichment Exercises

SOME OF THE MOST IMPORTANT FEEDBACK LOOPS regarding forests and climate are not included in Activity 5 because they are occurring on a global scale rather than on the scale of a single forest. In the systems enrichment options for this activity, students can explore these broad-scale feedback loops in more detail.

In **Feedback Loops in the News** students read a *New York Times* article in which writer Justin Gillis identifies feedback loops on a global scale. After reading the article, students draw a systems diagram, showing the relationships suggested in the article, and use that article to discuss the role that feedback loops play in the behavior of the system. See the instructions on the Activity 5 webpage for more details.

In **How Earthworms Got Me into College** students read a story that exemplifies a recurring lesson in systems thinking: how seemingly small changes can turn into large changes as they ripple through an entire system. In this story the narrator learns about the broad impacts that seemingly unimportant species—earthworms—can have on an entire forest ecosystem. Students use a causal loop diagram to understand the web of cause-effect relationships in the forest ecosystem. Other links are provided for instructors who wish to pursue these examples further. See the instructions on the Activity 5 webpage for more details.

In the **PINEMAP Focus on Research** video on the Activity 5 webpage, you can learn about a study exploring the interactions between fertilization, water flow in loblolly pine trees, and reduced rainfall (manipulated by throughfall exclusion structures, shown here).

ANDY LAVINER, VIRGINIA TECH

My Land Plan: Resource for Woodland Owners
American Forest Foundation
http://mylandplan.org
This website is a resource for individual woodland owners to aid in the management of their land. The site offers a land-planning tool that includes a mapping feature for customized woodland information.

Protecting Your Forest Asset: Managing Risks in Changing Times
Southern Regional Extension Forestry, 2013
http://sref.info/resources/publications/protecting-your-forest-asset
This pamphlet reviews healthy forest strategies and approaches to decrease the risks associated with projected climate change impacts.

Southern Forest Futures Project
U.S. Forest Service
www.srs.fs.usda.gov/futures
This website provides summary reports, a webinar, and other resources related to a multiyear research effort that forecasts changes in southern forests between 2010 and 2060.

Sustainable Tomorrow: A Teacher's Guidebook for Applying Systems Thinking to Environmental Education Curricula for Grades 9-12
Association of Fish and Wildlife, 2011
http://www.fishwildlife.org/files/ConEd-Sustainable-Tomorrow-Systems-Thinking-Guidebook.pdf
This guidebook provides descriptions of systems concepts and tools to help teachers in-tegrate systems thinking into their instruction.

Systems Thinking Essay
The Center for Ecoliteracy
www.ecoliteracy.org/essays/systems-thinking
A short essay that describes how ecological understanding requires shifting to a new way of thinking.

Systems Thinking in Action
Pegasus in Communications
www.pegasuscom.com
This website provides tools, resources, and information about systems thinking and organizational learning. Information about some of the basic concepts and tools used by these approaches can be found under the "Learn More" tab on the website homepage.

Forest Systems Diagram

NAME DATE

Use these variables to create a forest systems diagram by adding arrows to depict direct effects. Label the arrows with an S for SAME or an O for OPPOSITE to describe how one variable changes another. Only some variables and connections are illustrated here to emphasize relationships that play particularly important roles by influencing tree growth.

Private Family Landowner


SHELBY KRANTZ, UNIVERSITY OF FLORIDA

Landowner Doug Moore manages his forest for both timber and wildlife.

DOUG MOORE IS A LIFE-LONG RESIDENT OF JACKSONVILLE, Florida, and was a third generation dairy farmer until 2004. He phased out of the dairy business because of the urban development in his area. He wanted to stay in agriculture and had always wanted a big piece of timberland. There was a lot of timberland being sold by the forest companies in Baker County, and he purchased 2,400 acres in 2002.

Mr. Moore wants to balance the benefits of both forestry and wildlife on the land he purchased. He is interested in both wildlife and timber management because his family needs the timber income, and he also loves to hunt. While it would be nice to have plenty of money and manage the forest only for wildlife, the timber income allows him to pay for the property, taxes, and necessary management practices. He thinks landowners can manage for both objectives without sacrificing either one of them very much.

Prescribed burning is one of the most beneficial management treatments for wildlife, and it also lowers his risk for wildfires and reduces the understory competition that impacts tree growth. As a certified prescribed burn manager, Mr. Moore has established a regular burning schedule on the property.

Since he acquired the property, he has had the opportunity to harvest trees. As soon as he started cutting timber, he planted food plots to attract wildlife. In the open areas where trees were piled during the harvest, he removed the stumps and added lime to improve the soil nutrients. He used his farming background to create 40 different food plots on about 50 acres. When he replants trees, Mr. Moore uses a range of genetically diverse seedlings.

He also thins the forest, which is beneficial for wildlife and timber. He typically removes the slow growing and diseased trees and never lets the forest get too crowded or stressed. He conducts the first thinning when the trees are about 17 years old. In addition, three to four years later, he comes back and takes out trees that he can sell for pulpwood. He cuts the forest back from 400 trees per acre to about 250 trees per acre. This allows the remaining trees to grow larger and produce more timber. Simultaneously, he does some additional burning, which benefits the wildlife.

Thanks to Doug Moore, landowner, for sharing this information about his forestland in Northeast Florida.

Climate Scenario Cards

Use these variables to modify your a forest systems diagram by adding arrows to depict direct effects. Label the arrows with an S for SAME or an O for OPPOSITE to describe how one variable changes another. Only some variables and connections are illustrated in the Forest Systems Diagram to emphasize relationships that play particularly important roles in influencing pine tree growth.

	Climate Scenarios	Variables for Your Forest Systems Diagram
1	Increased carbon dioxide in the atmosphere enables Mr. Moore's trees to grow faster until other factors limit growth. What should Mr. Moore do to adjust to this change?	CARBON DIOXIDE
2	A decrease in summer rainfall has reduced the amount of groundwater available for the trees in Mr. Moore's forest. How should he respond?	PRECIPITATION, GROUNDWATER
3	Less rain has fallen recently, but the understory of Mr. Moore's forest is thick and tall. What should Mr. Moore do?	PRECIPITATION
4	Increased temperatures have resulted in a longer growing season with high precipitation. How should Mr. Moore respond to these changes?	PRECIPITATION, TEMPERATURE, LENGTH OF GROWING SEASON
5	There have been more severe storms. These storms have damaged trees in Mr. Moore's forest, and the weakened trees could attract pests that carry disease.	SEVERE STORMS
6	Mr. Moore has been observing warmer winter temperatures this year, which have caused an increase in tree fungi that cause disease. How are these changes likely to impact the forest? What should Mr. Moore do?	TEMPERATURE, FUNGI
7	Rapid changes to climate patterns have caused increased uncertainty regarding the amount of precipitation each year. What can Mr. Moore do to adjust to this increased uncertainty?	PRECIPITATION, GROUNDWATER

Management Cards

Use these variables to modify your a forest systems diagram by adding arrows to depict direct effects. Label the arrows with an S for SAME or an O for OPPOSITE to describe how one variable changes another. Only some variables and connections are illustrated in the Forest Systems Diagram to emphasize relationships that play particularly important roles in influencing pine tree growth.

THINNING helps reduce competition between trees and promotes growth of the remaining trees by increasing the light and nutrients they receive. Thinning can also increase the amount of water that each tree obtains. As a result, reducing forest density reduces the risk of insects, disease, and wildfires. Properly managing forest density through thinning is critical for maintaining the health of our forests.	**THINNING**
PRESCRIBED FIRE is an important tool to reduce fuels and the risk of wildfire, reduce invasive plants and insects, improve wildlife habitat, and maintain native forest ecosystem health. However, changes in temperature, precipitation, and storm events may reduce opportunities to use prescribed fire safely. Wildfire risk increases with elevated summer temperatures and reduced rainfall during the growing season.	**PRESCRIBED FIRE**
INCREASING GENETIC DIVERSITY by planting seedlings from different species or different families of a single species may help forest owners prepare for uncertainty. In some situations, forests with some variation in genetic diversity may be more resilient and better able to withstand uncertain environmental changes than forests with little genetic diversity. Species and families differ in their ability to grow under different climate conditions. Species with larger geographic ranges, and therefore with the genetic potential to tolerate a wider variety of conditions, may offer less risk than species with narrowly defined ranges.	**GENETIC DIVERSITY**
FERTILIZING a forest once or twice in the lifetime of the trees encourages more rapid tree growth in places where nutrients such as nitrogen and phosphorus are naturally limiting in the soil. Landowners must be careful to only apply minimal amounts of fertilizer and not let it drift into streams or wetlands. Maintaining vigorous growth of the trees makes them less susceptible to insect attacks and drought. Prices of fertilizer may increase as fossil fuel prices climb, making it more costly to manage for proper tree nutrition.	**APPLY FERTILIZER**

ACTIVITY 6

Mapping Seed Sources

Students use growth data from loblolly pine forests to identify genetically different populations and project where trees with certain characteristics are likely to thrive in changing climatic conditions.

Subjects
Agriculture, Biology, Environmental Science

Skills
Analyzing Data, Determining Cause and Effect, Identifying Relationships and Patterns, Interpreting

Materials
Student pages, answer keys, and presentations (see Activity Webpage link below); graph paper; access to Microsoft Excel® (optional)

Time Considerations
One to three 50-minute class periods

Related Activities
This activity applies concepts of heredity to forests. Students may appreciate an introduction to forests and climate (Activities 1 and 3). It can be followed with additional strategies that forest landowners can use to create resilient forests (Activities 4 and 5).

Research Connection
By studying genetic traits, scientists can develop tree-breeding programs to identify parent trees that will produce seedlings that are better able to thrive in future climate conditions.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section2/activity6

Objectives

By the end of this activity, students will be able to

- state two reasons for variation in growth of loblolly pine across its range, and
- explain the value of maintaining genetic diversity within a population as climate becomes more uncertain and variable.

Assessment

- Assess responses on student pages for identification of population source of each genetically related family and for responses to the writing prompt.
- Ask students to write a short essay explaining why the natural population of loblolly pine contains two relatively distinct populations, how the eastern and western populations differ, and how these differences might benefit the species' survival.

Background

How a tree grows is a function of its environment and genetic makeup. Whether a tree gets full sun or too much shade, a lot of rainfall or not enough, or is exposed to a horde of tree-eating insects is a function of its environment. But ***genes*** can predispose a tree to function a certain way in a variable environment. Traits such as growth potential, form, ability to tolerate drought, and disease resistance are controlled by many genes. These genes are not located on a single ***chromosome*** like the gene that controlled flower color in Mendel's famous peas. Because many genes on different chromosomes are involved in a trait such as tree growth, it is difficult to identify which genes control the trait. One way to better understand the genetic variation is to test different individuals and ***families*** of trees in multiple environmental conditions in order to determine which trees perform well in specific environments. These tests have been used extensively to rank the growth performance of individuals and families that were collected from different environments across the natural range of loblolly pine (*Pinus taeda*). A family consists of individuals that share one or both parents. It may be helpful to think of individuals in a family as siblings, similar to human brothers and sisters. Parents whose offspring (***progeny***) have outstanding individual traits, or ***phenotypes***, are then used to provide seeds for planting and are bred together to create genetically improved populations or families. Eventually, when technology improves to the point that important genes can be identified, researchers will breed individuals with suites of genes to create new seedlings with the desired combinations of characteristics.

Additional background information can be found in the **Section 2 Overview**.

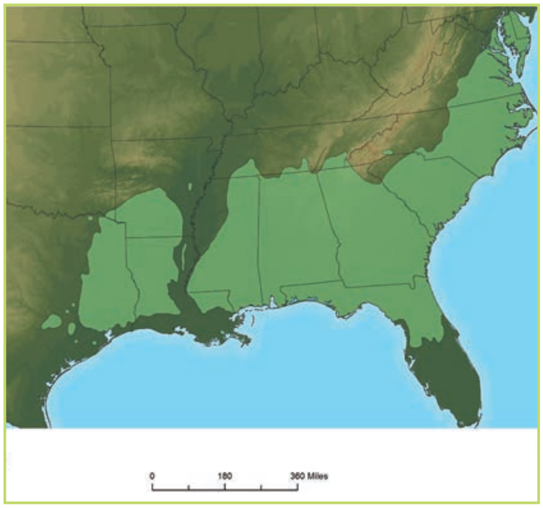
Loblolly pine is a native tree ***species*** whose natural range in the southeastern United States is separated by the Mississippi River valley into two populations. The genetic makeup of these two populations is significantly different, though there is some blending at


JOHN SEILER, VIRGINIA TECH

How a tree, such as this young loblolly pine, grows is a function of the environment in which it grows and its genetic makeup.

the edges of the river valley where pollen from the west fertilizes cones on the edge of the eastern zone. This genetic difference began thousands of years ago during the most recent Ice Age when glaciers covered northern North America and pushed native plants and animals south. The eastern loblolly pines survived by moving into Florida and the Caribbean Islands. Other loblolly pine trees in the west migrated into Mexico and Central America. While the trees were separated geographically, their genetic makeups diverged through natural selection, which allowed individuals with the highest ***genetic fitness*** in each ***climate*** to reproduce more often than those with a less appropriate set of ***alleles,*** which reproduced less effectively or died. After thousands of years, the glaciers receded, and loblolly pines slowly returned to their current natural range in the southeastern U.S., with the western population moving up from Mexico and the eastern population from the Caribbean and South Florida (Schmidtling et al., 2000).

In the western population, the trees tolerate drought significantly better than those in the eastern range. Compared with the western population, the eastern trees grow taller and faster with adequate rain. Forest researchers are looking for genes across both populations and testing which trees will tolerate the conditions that a future climate may bring to the region. They are also breeding trees with these superior characteristics to develop seedlings that will tolerate drought and still grow quickly (Lambeth et al., 2005). Since these traits are controlled by many different genes, the offspring from one parent from the western population and one from the eastern population are expected to produce offspring that exhibit a range of possible ***phenotypes***. Just like some brown-eyed parents could produce blue-eyed children (if the parents are ***heterozygous***—meaning the individuals have different alleles for the particular trait), the ***genotypes*** in the tree offspring will exhibit the full complement of traits. For example, some may be drought-susceptible and fast-growing; others may be more drought-tolerant and fast-growing. Breeders select the best parents and cross them to produce offspring for the next generation with the goal of growing at least some trees with an improved set of characteristics for future forests.



WADE ROSS, UNIVERSITY OF FLORIDA

Ranges of eastern and western populations of loblolly pine trees.

In this activity, students use tree height data from six families planted at three test locations across the entire range. By relating tree size and survival with average rainfall, they discover patterns of drought tolerance and growth and identify two distinct populations.

Teaching This Content

This activity provides a real and practical application of concepts and information related to genetics. It is a great follow-up to a basic genetics unit. In addition, this activity engages students in creating and interpreting column graphs. Students and teachers may need a quick refresher to be reminded of graphing skills. On the Activity 6 webpage, you will find a short video and a presentation with teacher notes to help you provide a brief overview of creating column graphs.

Getting Ready

The Activity 6 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section2/activity6).

You may want to provide an overview of forests and forests management by using Introduction to Southeastern Forests presentation on the Activity 6 webpage.

TEACHERS SAY …

This activity provides a great opportunity to have my semi-urban students understand more about forestry in the Southeast.

—Agriscience/Horticulture Teacher, Florida

Systems Thinking Connection

IN THIS ACTIVITY students learn about the importance of maintaining a genetically diverse population. Systems thinkers explain this importance in terms of a concept called ***resilience***—the ability of a ***system*** to tolerate disturbances without changing into a completely different system, such as a forest eventually becoming a field if all the trees fail to reproduce. It is common to manage ***plantation*** forests for maximum ***timber*** production by planting progeny from specific parents that grow fast and are best suited to tolerate environmental conditions at the forest location. One potential concern with this approach is that we cannot exactly predict future conditions. If unexpected changes occur, the planted trees may no longer grow as well at that location.

In situations involving high levels of uncertainty, many forest managers take steps to minimize risk. By maintaining some ***genetic diversity,*** a forest manager accepts the fact that some trees are going to grow slower than others under the current conditions. However, if environmental conditions change (e.g., become drier), trees that were not growing as well before may become the most productive in the plantation. Managers have developed multiple strategies for hedging their bets in the face of climatic uncertainty (Millar et al., 2007). Instructors may want to emphasize that managers and landowners must balance the goal of forest ***productivity*** today with the goal of decreasing the risks associated with changing future conditions.

TEACHERS SAY …

I went over graphing basics, assigned this activity as homework, and we discussed it the next day. Students were able to extrapolate the data needed and to interpret their graphs.
— Biology Teacher, Kentucky

Make copies of the student pages for each student.

Set up Microsoft Excel® in the computer lab or obtain graph paper for students. You may want to use the Creating Column Graphs in Excel presentation on the Activity 6 webpage if your students are unfamiliar with using this program.

Note: This exercise is somewhat simplified to help students understand the role of genetic research in forestry. The patterns observed in this exercise illustrate a general rule for the performance of two distinct seed sources. Pine trees are extremely variable, making it possible to identify outstanding trees from almost any seed source. Forest geneticists and tree improvement practitioners use selection and progeny testing to make these identifications and to refine their plans to distribute viable seeds.

Doing the Activity

1. If students are not familiar with southern pine trees and forest management in the Southeast, you can provide a brief overview of this topic using the Introduction to Southeastern Forests presentation, available on the Activity 6 webpage.

2. Provide an introduction or refresher to how genetic variation and natural selection affect populations of plants and animals. If students have studied genetics, ask them to recall some traits that are controlled by one gene with several alleles (eye color in people and flower color in sweet peas). Explain that other traits, such as body type or height in humans, are governed by a host of genes as well as environmental conditions. Even when the environment is controlled and people eat exactly the same thing, some people will grow differently than other people because of their genetic makeup. Trees are like that too.

3. Explain to students that the yield of wood from an acre of land is related to the number of trees that survive to harvest and the size of the trees. For example, 150 tons of wood from one acre can come from 300 trees that have an average diameter of 25 centimeters (cm) or 200 trees that have an average diameter of 30 cm, even if they are all the same age.

4. Ask students what they already know about the traits that might be important in trees, such as loblolly pine, that are grown for paper and lumber. This pine species is grown in plantations across its range from Virginia to Texas and also is found in naturally regenerated forests. You might find these discussion questions helpful:

- What traits are important to landowners who sell trees?
  Fast growth, straight growth, few branches, survival under stressful conditions, quick response to fertilizer, resistance to fire and disease, and wood density are important qualities.

- How can people obtain these traits for their trees?
  If forest managers save the seeds from trees that have an excellent form, they can grow seedlings in a nursery and make those particular traits available to more forest landowners.

5. Use the information in the activity background to explain to students that there is genetic variation across the population of loblolly pine—some trees have the potential to grow quickly while other trees tolerate drought better. These differences are due to natural selection. Natural selection favors trees that are more reproductively successful, i.e., trees that reach sexual maturity earlier and that survive the longest. Foresters favor trees with economically important characteristics, i.e., fast growth and straight stems. Most traits are not mutually exclusive and many traits are favored by both natural selection and by foresters. For example, disease resistance and adaptability help trees survive to reproduce and provide an economic value favored by humans.

Another example is that natural selection favors trees with greater drought tolerance in more drought-prone regions, which means on average that trees from these regions will survive better and reproduce more. In this way nature selects for trees adapted to thrive with less rainfall. Researchers study how well trees grow in many different areas of the Southeast and look for the trees with the optimal combination of adaptive and economically important traits. Forest researchers spend a lot of time in the woods measuring trees. They apply different types and rates of fertilizer and note which trees grow the most quickly. Since they return to the same trees each year, they establish permanent plots in the forest, similar to those students learn about in **Activity 8: Counting Carbon**. Since the plots are of a known size, the researchers can measure the sample of trees and then estimate the growth of similar trees in a larger area under similar climatic conditions. In the following example data, trees from west of the Mississippi River will tolerate drought better than trees east of the river.

6. Ask students to work in groups or individually based on how well your students can accomplish these tasks. As you distribute the student page, explain that these numbers are from researchers who are conducting a study where they have planted trees from six families (and each family is genetically related, with the individuals sharing one or both parents) at three different research stations. The first column identifies the location and average annual rainfall. The second column identifies the family. The remaining two columns provide the average survival as a percentage of the original number of trees planted and the average height of surviving trees after ten years of growth in the field. Each row provides these data for each family. Researchers collect data just like these and then look for patterns and relationships to understand more about the trees and conditions in which they grow best. However, one key piece of information is missing from this data set—information about which population is the original source of the genotypes (eastern or western). That is what students will be able to predict after graphing these data and examining patterns.

7. Ask students to make three double-column graphs, one for each site, with the families on the *x*-axis and both survival percent and height on the *y*-axis. It may help to keep survival and height in two different colors. Ask them to look at the patterns and determine which families are responding similarly to rainfall and are probably related. Ask students to predict which families came from the western population and which from the eastern population. Completed graphs are in the answer key, which can be found on the Activity 6 webpage.

Students should notice that at the site with an average of 130 cm of rainfall per year all families have high survival rate and families A, C, and E are slightly taller than families B, D, and F. At the drier site with an average of 100 cm of rainfall per year the survival rate of families A, C, and E is poor while families B, D, and F do much better. The trees in families B, D, and E are slightly taller compared with A, C, and E during drought conditions.

8. Ask students the following questions:

- Why do you think all families have high survival and the best growth at an average of 130 cm per year of rainfall?
  This amount of rain is not a limiting factor; all families will do well with adequate rainfall.
- Which families are likely to be from the western loblolly population and which ones from the east? Why?
  Western: B, D, and F. Eastern: A, C, and E. The site with 100 cm of rainfall shows a clear difference in survival when water is limited (B, D, F do well and are also taller). The site with 130 cm of rainfall demonstrates greater height for families A, C, and E.
- If you were a forest landowner today in Texas, would you plant trees from families

The **Introducing Column Graphs** video on the Activity 6 webpage explains how to create column graphs from data tables.

TEACHERS SAY …

Some students had difficulty interpreting the data, but that's what I loved. This is a great assignment to work on students' data-analysis skills.

— *AP Environmental Science Teacher, Florida*

from the eastern or western populations?
Western.

- If you were a forest landowner in Georgia, would you plant trees from families from the eastern or western populations?
Eastern.
- In areas where less rainfall is likely in the future, based on climate change models, which families would be better able to survive?
Western.
- What are the disadvantages of planting a forest of only one family or genotype?
If they are susceptible to a disease, they could all die. Therefore, planting only one family increases risk of catastrophic loss. Genetic diversity, even within a species, can help to decrease this risk.
- In areas where more rainfall is likely, which families should be planted?
Eastern.
- What are the disadvantages of this strategy?
If there is a prolonged drought, there may be a higher risk of losing a substantial number of trees.
- If you could pollinate eastern cones with western pollen, what types of trees would result?
All potential variations and combinations would result. Some trees will thrive in drought, some will grow well in wetter conditions, some will grow tall quickly, and some will not.
- Which ones would be ideal in an uncertain climate?
Those that tolerate drought, grow quickly in all conditions, and tolerate diseases.

9. Ask students to complete the writing assignment at the end of the student page, either in class or as homework. An ideal answer will suggest that because the landowner grew eastern and western trees in the same forest, they produced seeds that exhibited all of the traits of both populations, and a percentage (not all of them) of these offspring thrived better than either parent.

10. Systems Reflection: How can systems thinking skills help us maintain a system's resilience and avoid potential catastrophe?
By considering the variables within a system and the direct and indirect connections between variables, we can see how different actions or occurrences may affect the system. Causal loop diagrams are particularly helpful for exploring the relationships between variables (see Activity 5). These diagrams can help identify reinforcing feedback loops that might cause the system to behave in undesirable ways. They can also be used to identify how the forest management strategies can influence the system.

11. Summarize this activity by emphasizing that trees have certain genetic traits that make them more or less likely to survive and grow in future environmental conditions. For many years, scientists have been breeding trees to select for fast growth, high yields, and disease resistance. Given climate projections, scientists have more recently started exploring traits that might help trees survive under different climate scenarios. Can you think of other products where this type of research is very important (e.g., other crops we depend upon)? A video on the Activity 6 webpage enables your students to listen to a graduate student explain his research project focused on pine tree genetics.

Modifications

Students who have not learned about genetics in previous courses and/or those who are not familiar with how to create graphs will need additional instruction.

You can find a short video on the Activity 6 webpage that explains how to create column graphs from data tables. You may want to spread the activity over two or three days, so you can provide adequate background and examples.

Students can complete the graphing portion of the activity in groups, with each group completing one graph or a portion of the graph and then presenting it to the class.

Enrichment

Advanced students should be able to graph survival on the *y*-axis and height on the *x*-axis for each population. They can assess the strength of the linear association between survival and height by determining the coefficient of determination (R^2). The coefficient of determination provides the proportion of variation in one variable that is explained by another variable and can be shown as a percentage between 0 and 100 or as a decimal between 0 and 1.00. The Calculating Coefficient of Determination presentation on the Activity 6 webpage provides a quick "how-to-guide" for calculating the coefficient of determination using Microsoft Excel®. A coefficient of determination greater than 0.5 suggests that there is an association between survival and height, while a correlation coefficient of less than 0.5 is weaker, suggesting that variation in survival is not well explained by height; surviving trees may be shorter or taller. Which trees would a tree farmer prefer to plant? See the answer key on the Activity 6 webpage.

Ask students to go to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) website (http://www.sgcp.ncsu.edu:8090) and explore the projected climate for your region. This is a site that enables foresters to assess the possible climate futures and make forest management projections. Would genes from eastern or western families of loblolly pine be useful to help trees thrive in your area?

STEVE MCKEAND, NORTH CAROLINA STATE UNIVERSITY

Tree measurements are taken on 4-year-old loblolly pines at a test site near Oliver, Georgia.

Additional Resources

A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States
Anantha Prasad, Louis Iverson, Stephen Matthews, and Matthew Peters; U.S. Forest Service
http://www.nrs.fs.fed.us/atlas/tree
This searchable database provides information on 134 common trees in the eastern U.S. The key feature is the presentation of data for each species describing both the current distribution of that species and future suitable habitat based on climate change models. This website is featured in **Activity 3: Atlas of Change.**

SHELBY KRANTZ, UNIVERSITY OF FLORIDA

In the **PINEMAP Focus on Research** video on the Activity 6 webpage, a graduate student shares information about a forest genetics research study.

Learn Genetics
Genetic Science Learning Center, University of Utah
http://learn.genetics.utah.edu
This interactive website provides an overview of genetics, heredity, traits, and other genetics-related topics. Teaching materials are also provided.

Southern Pine Seed Sources, General Technical Report SRS-44
Ronald Schmidtling, U.S. Forest Service, 2001
www.srs.fs.usda.gov/pubs/2797
This report provides guidance on selection of seed sources for six species of southern pine trees.

Template for Assessing Climate Change Impacts and Management Options (TACCIMO)
U.S. Forest Service
www.sgcp.ncsu.edu:8090
This web-based tool, intended for use by land managers, provides the most current climate change projections and research in an effort to link science to forest management and planning. Features include a geospatial mapping application, a searchable listing of peer-reviewed literature, and guides explaining how to use TACCIMO.

Trees Grow throughout Southeast with Help of UF
University of Florida
http://www.ufl.edu/spotlights/archives/trees-grow-throughout-southeast-with-help-of-uf.html
This short video introduces the work of the Cooperative Forest Genetics Research Program at the University of Florida, where researchers study tree breeding to improve tree growth and disease resistance in order to meet increasing demands for wood products.

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Forest Growth and Rainfall Data (1 of 2)

NAME DATE

Imagine that forest researchers at three research stations in the Southeast planted loblolly pine trees 10 years ago. At each location, they planted six different families of loblolly pine trees. The families are groups of individuals that are genetically related because they share one or both parents. Some of these families originated from western populations of loblolly pine forests and some families originated from eastern populations. For 10 years, forest scientists collected data for the families at each site including rainfall, tree survival, and tree height.

The table below summarizes the results for survival and height for families at the three locations.

- Column A provides the site number and average annual rainfall at each location for years 1 to 10.
- Column B identifies the family.
- Column C is the average percent of the trees planted that are still alive after 10 years.
- Column D is the average height of surviving trees after ten years of growth.

A: Location and Average Rainfall (centimeters, cm)	B: Family	C: Percent Survival at Year 10	D: Average Height at Year 10 (meters, m)
Site 1: 100 cm per year	A	40	6
	B	80	9
	C	20	5
	D	75	10
	E	10	8
	F	60	9
Site 2: 115 cm per year	A	80	13
	B	90	9
	C	75	12
	D	86	11
	E	40	14
	F	75	11
Site 3: 130 cm per year	A	90	15
	B	90	11
	C	88	14
	D	88	12
	E	92	15
	F	92	12

Forest Growth and Rainfall Data (2 of 2)

1. Use the data table to make three graphs, one for each site. Column graphs with two y-axes will be easiest to interpret. For each graph, place the families on the x-axis, percent survival on the left y-axis, and height on the right y-axis. You will have two columns for each family (one for percent survival and one for average height). Include a key to indicate which column is percent survival and which column is height and label the units and axes.

2. The data table is missing important information! We don't know which families came from the western population of loblolly pine trees and which came from the eastern population. Use your graphs and what you know about the average annual rainfall at each site to predict which families came from the western population and which families came from the eastern population. Remember that families that came from the western population can survive with less rainfall, while families from eastern populations grow faster with adequate rainfall.

   For each family, write the original source of the genotype (eastern or western population).

   A: ____________________ B: ____________________ C: ____________________

   D: ____________________ E: ____________________ F: ____________________

3. Given what you know about the different growth patterns of eastern and western populations of loblolly pine, respond to the following writing prompt:

   It is 2050. You've been invited to an awards ceremony honoring an elderly forest landowner who is regionally known for his wood production. Many of his trees survive changes in climate, and a large number of them are taller than everyone else's. Unfortunately, the landowner is unable to attend the ceremony and you have been asked to substitute for him. The organizers would like you to explain why he was able to grow trees better than anyone else. You happen to know that this landowner has a brother in Texas and another in South Carolina who both grow loblolly pine trees. About 50 years ago he planted trees from both brothers on his property. You agree to explain to the audience what this landowner did that enabled his trees to thrive two generations later.

SECTION 3

Carbon Sequestration

Forests can be managed to reduce atmospheric greenhouse gases.

CO_2

CARBON, OFTEN CALLED THE BUILDING BLOCK OF LIFE, continuously cycles through all plants, animals, soils, rocks, oceans, and the ***atmosphere***. Carbon is found everywhere on Earth, and it undergoes chemical reactions and changes forms as it moves. For example, carbon

- resides in the atmosphere as ***carbon dioxide*** (CO_2);
- is formed into diamonds, one of the hardest substances on earth, and graphite, the soft lead in a pencil;
- provides the structure of plants as cellulose and lignin;
- is stored in starches and sugars that can be broken down to provide organisms with energy for cellular functions;
- resides in every living plant and animal, in the soil, and in the oceans;
- becomes calcium carbonate to form coral reefs and marine animal shells; and
- transforms to calcite in ***limestone***.

In addition, fossilized carbon or ***fossil fuels***, such as coal, oil, and natural gas, are burned as fuel to power the human world. Fossil fuels are used for many activities, such as operating machinery, turning on lights, and flying airplanes. Fossilized carbon is also commonly used to make the fertilizer that helps us grow food efficiently, plastics that keep hospital supplies sterile, and even the packaging that keeps vegetables fresh.

Carbon naturally cycles through biological, physical, and geological ***systems***. However, humans have been altering these systems by adding more carbon to the atmosphere in various ways, most notably through extraction and use of fossil fuels for energy. Atmospheric carbon dioxide has been gradually increasing since the Industrial Revolution (roughly 1760 to 1840), when people began burning fossil fuels in great quantities. In addition, ***deforestation*** increases carbon dioxide levels in the atmosphere, as this action changes landscapes that sequester and store carbon into landscapes that sequester far less carbon, such as agricultural lands or urban developments. As atmospheric carbon increases, most scientists agree that the average global temperature will also increase (U.S. GCRP, 2009). This happens because carbon dioxide, along with other ***greenhouse gases,*** such as methane, nitrous oxide, and water vapor, trap heat in Earth's atmosphere. This process is known as the ***greenhouse effect.*** See the Background section for **Activity 2: Clearing the Air** for more information on climate change science.

Carbon is found everywhere on Earth, and it undergoes chemical reactions and changes forms as it moves.

JOHN SEILER, VIRGINIA TECH

One strategy to reduce carbon dioxide in the atmosphere is to plant and grow more trees so they can sequester and store carbon.

Oceans can also be affected by increased levels of atmospheric carbon because these large bodies of water continuously exchange carbon with the atmosphere. As the amount of carbon in the atmosphere increases, the amount of carbon dissolved in the oceans increases. This causes the ***pH*** of the water to become more acidic. Continued ***ocean acidification*** can affect the health of marine organisms. In particular, organisms that build shells or skeletons containing calcium carbonate, such as coral reefs, clams, and oysters, may be negatively impacted because decreases in ocean water pH will mean that there is less carbonate available for these organisms to build their hard body parts.

As all systems on Earth interact and influence one another, scientists around the globe are researching the potential impacts of a changing average global temperature and ocean water pH. These impacts can be diverse and may involve changes in ***weather*** patterns, sea levels, ***ecosystems***, and plant and animal populations. Strategies to cope with these changes (***adaptation*** strategies) are important. In addition, experts, engineers, policymakers, and communities are working to develop strategies to *reduce* carbon dioxide in the atmosphere (***mitigation*** strategies). Some mitigation strategies include planting and growing more trees to capture more carbon, keeping carbon stored in wood products, capturing carbon and pumping it into the ground, reducing our dependence on fossil fuels, and increasing energy efficiency.

ACTIVITY 7: Carbon on the Move provides an introduction to the ***carbon cycle***, with an emphasis on the role of forests in the cycle. The first portion of the activity focuses on the pools and fluxes of the biological carbon cycle. This is followed by group work and class discussion that include the geological carbon cycle.

Understanding how biological, geological, and atmospheric systems interact through the carbon cycle is a key component to understanding climate change.

ACTIVITY 8: Counting Carbon provides students with an understanding of the role that forests can play in reducing atmospheric carbon dioxide. Students measure trees near their school and calculate the amount of carbon stored in each tree. Students then calculate the amount of carbon being sequestered per year by different land uses in their state. They also compare the amount of carbon that is emitted in their state to the amount of carbon that can be sequestered and consider the implications of the difference.

Potential Areas of Confusion

There are several topics in this section that may be sources of confusion for students based on their existing knowledge, assumptions, or prior experiences. You may be able to use questions to uncover these points of confusion and steer students toward the clarifications provided in the table.

Assumption or Confusion	More Adequate Conception
Plants release oxygen, not carbon dioxide. Or if they do release carbon dioxide, they only respire in the dark.	Plants capture carbon dioxide from the atmosphere during the day, store it in sugar molecules, and then continually break down those sugar molecules to create energy in the form of a chemical compound called ***ATP (adenosine triphosphate).*** ATP is then used to build and maintain complex structures such as cellulose, lignin, bark, and leaves from the simple sugars made in ***photosynthesis.*** The process of metabolizing sugars ***(respiration)*** releases carbon, which returns to the atmosphere as carbon dioxide. This occurs throughout the day and night.
Animals need oxygen, and plants need carbon dioxide.	Plants require carbon dioxide, but they also need oxygen during the process of respiration. Generally, plants release more oxygen as a byproduct of photosynthesis than the amount they use to respire. Woody plants in particular use more carbon dioxide than they release.
Gases are not matter or they don't have mass.	Anything that has matter has mass. Frozen, compressed carbon dioxide is called dry ice and has mass. Gases have mass, too, just less than solids or liquids (by volume) because the molecules are farther apart.
The food broken down for energy leaves an animal's body entirely through its urine and feces.	Much of the substance of food leaves the animal as exhaled carbon dioxide, which is a byproduct of energy-producing cellular respiration.
Respiration produces energy, rather than converting energy.	Respiration converts energy from one form to another.
Energy is used up during biological processes.	Energy cycles. "Used" energy becomes waste heat.
Gases such as carbon dioxide lack sufficient mass to lead to the development of biomass in plants. Plants get mass from the soil.	Plants create biomass from a gas (CO_2) and water (H_2O) by removing carbon and oxygen from carbon dioxide, and hydrogen from water, and then bonding these atoms together to make sugars and cellulose.
Carbon and carbon dioxide are the same thing.	Carbon is an element. When one molecule of carbon combines with two molecules of oxygen, the chemical compound carbon dioxide is formed. At standard temperature and pressure (STP), carbon dioxide is a gas typically found in Earth's atmosphere. Carbon dioxide can also exist as a liquid or solid.

(Table adapted from Hartley, Wilke, Schramm, D'Avanzo, & Anderson, 2011)

The activities in Section 3 help students understand how forests can reduce atmospheric greenhouse gases through carbon sequestration.

VIRGINIA STATE UNIVERSITY

Key Concepts in This Section

- Carbon naturally cycles through biological, physical, and geological systems.
- Humans are altering the natural carbon cycle by adding more carbon to the atmosphere, primarily through fossil fuel combustion.
- Increased levels of atmospheric carbon dioxide will impact other systems, including oceans and forests.
- Trees absorb carbon dioxide from the atmosphere during the process of photosynthesis. About half of this carbon is stored or "sequestered" in the tree's growing roots, trunk, branches, and leaves.
- Southern pine forests are a particularly effective landscape for sequestering carbon because of the trees' fast growth rates.
- There is not enough land available on Earth for forests to sequester all the carbon dioxide that we emit through industry, transportation, and other activities. To reduce atmospheric carbon, we might consider solutions such as reducing consumption and using low-carbon energy sources.

References Cited

Hartley, L. M., Wilke, B. J., Schramm, J. W., D'Avanzo, C., & Anderson, C. W. (2011). College students understanding of the carbon cycle: contrasting principle-based and informal reasoning, *BioScience, 61,* 65–75.

U.S. Global Climate Research Program (U.S. GCRP). (2009). *Global climate change impacts in the US.* Washington, DC: Cambridge University Press. Retrieved from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

7 Carbon on the Move

Students imagine they are a carbon atom and take part in a simulation that allows them to cycle through biological and physical systems. Group work and class discussions allow students to better understand global carbon pools, quantities, fluxes, and residence time—with an emphasis on how human activities can affect where carbon goes.

Subjects
Agriculture, Biology, Chemistry, Earth Science, Environmental Science

Skills
Determining Cause and Effect, Identifying Relationships and Patterns

Materials
Student pages, answer keys, and presentations (see Activity Webpage link below); eight dice; large paper; markers

Time Considerations
Part A: One 50-minute class
Part B: One 50-minute class

Related Activities
This activity introduces the carbon cycle. It can be preceded or followed with information about climate change (Activity 2) and followed with Activity 8, which applies this information to understanding carbon sequestration across the landscape. This activity also provides helpful background to Activity 12, which explores the life cycle of wood products.

Research Connection
Scientists are studying the amount of carbon that is stored in different carbon pools, how carbon moves between different pools, and the length of time that carbon resides in these pools. This information is key to understanding how carbon dioxide emissions affect the carbon cycle on Earth.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section3/activity7

Objectives
By the end of this activity, students will be able to
- illustrate the carbon cycle, including carbon pools and carbon fluxes;
- explain how the biological carbon cycle is "in balance;" and
- predict how releasing carbon stored in fossil fuels affects other carbon pools.

Assessment
- Use the group carbon cycle diagram to assess students' understanding of the major carbon pools and carbon fluxes.
- Instruct students to write a summary of what they learned during the carbon cycle exercise and subsequent group work and discussion. Ask them to address the following: What is the biological carbon cycle, and how does it differ from the geological carbon cycle? What are potential effects of releasing carbon stored in geological pools?

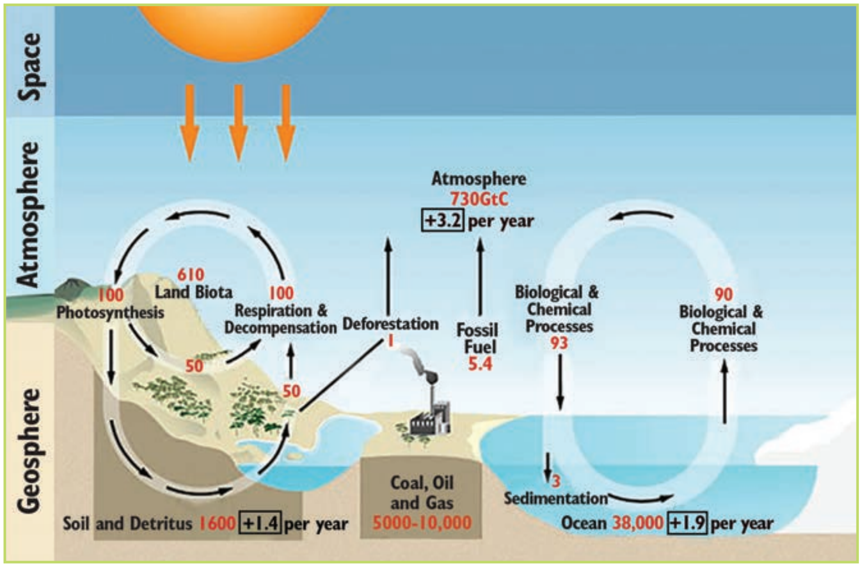
Background

Carbon flows through biological, physical, and geological ***systems*** with different processes and at different timescales. The ***carbon cycle*** refers to the movement of carbon, in its various forms, from one pool to another (figure 1). A ***carbon pool*** is any place where carbon can be found, such as plants, the ***atmosphere,*** or soil. Carbon pools can also be called ***stocks*** or reservoirs. ***Carbon flux*** is the process by which carbon moves from one pool to another. For example, carbon moves from the atmosphere to plants through ***photosynthesis*** and can move back from plants to the atmosphere through plant or soil ***respiration*** during the ***decomposition*** process, or during a ***wildfire*** when trees and plants are burned. When a pool absorbs more carbon than it releases, it is a ***carbon sink***. For example, the ocean and soil are carbon sinks. Forests can also be carbon sinks. Alternatively, when a pool releases more carbon than it absorbs, it is a ***carbon source***. Because ***fossil fuels*** cannot be created as fast as we are extracting and combusting them, they are considered a carbon source.

Additional background information can be found in the **Section 3 Overview**.

Biological Carbon Cycle
In the biological system, carbon cycles through living organisms, land, water, and the atmosphere by processes including photosynthesis, respiration, and decomposition. Different quantities of carbon reside in each pool, and the carbon moves at different rates among the pools. Some of these processes occur very quickly, while others can take hundreds to thousands of years. For example, some carbon atoms may cycle daily through plant photosynthesis and respiration, while other atoms may be trapped in a tree trunk for hundreds of years through carbon sequestration. Soil can also trap carbon for long time periods, up to thousands of years.

Carbon sequestration is the process of transferring atmospheric ***carbon dioxide*** into other pools, such as plant ***biomass*** via photosynthesis or into soils from decaying plant and animal matter.



COMMONWEALTH OF AUSTRALIA, BUREAU OF METEOROLOGY

Figure 1. The global carbon cycle, with amounts of carbon in carbon pools noted in gigatons (GtC) and carbon flux and accumulation rates noted in GtC/year.

WHAT IS A GIGATON?

It is a measure by weight, of one billion metric tons, which is the weight of one cubic kilometer of water. A metric ton is 2,200 pounds. One gigaton is about the amount of CO_2 emitted by all American adults driving 15,000 miles in average cars. For examples to visualize carbon dioxide emissions, go to www.carbonvisuals.com and www.carbonquilt.org.

Carbon storage in plant biomass is relatively easy to visualize as plants and trees are comprised largely of carbon that they have obtained from atmospheric carbon dioxide through photosynthesis. During photosynthesis, plants convert carbon dioxide and water into sugar in the presence of sunlight. Some of the sugars are used as building blocks to form plant biomass, such as cellulose, lignin, bark, and leaves. Through this process, carbon moves from the atmosphere and is stored in plant cells. Building and maintaining these complex structures requires energy, which the plants convert by metabolizing sugars made during photosynthesis to form ***ATP (adenosine triphosphate)***. ATP is created through the process of respiration, which releases some carbon dioxide back into the atmosphere.

Many people do not realize how important soils are in carbon sequestration. Carbon is a major ingredient of soil, and as figure 1 indicates, soil contains well over twice the carbon found in all the terrestrial plants and animals. As plants and trees grow, die, and decay, some of their carbon is stored in soils in "recalcitrant" forms that decay slowly. This carbon can build continuously over long periods of time and will likely play a significant role in carbon sequestration efforts. The deep ocean and soils represent significant carbon pools, where carbon can stay for hundreds to thousands of years. On the other hand, the exchange of carbon between the atmosphere and plants, along with the exchange between the atmosphere and the ocean's surface, occurs continuously. The amount of carbon flowing through the biological system without human impact (through plants and animals to soil and atmosphere) is fairly stable and is considered to be "in balance." In figure 1, the biological fluxes in terrestrial and marine systems account for all their carbon.

To distinguish between the mineral and organic components of soil, we refer to the decomposing, organic components as soil carbon.

Geological Carbon Cycle

The geological carbon cycle occurs over millions of years and includes processes such as rock formation, large-scale land shifts (plate tectonics), weathering, dissolution, volcanic eruptions, and fossilization. Fossil fuels—petroleum, natural gas, and coal—are created over hundreds of millions of years as layers of rock, soil, and ***sediment*** cover the remains of dead plants and animals. As this organic matter becomes compacted, pressure and heat turn the carbon into long chains of ***hydrocarbons***. Without human intervention, the carbon would mostly remain trapped far beneath Earth's surface—making fossil fuels a long-term carbon sink. ***Limestone*** is another long-term carbon sink. Limestone forms when ocean sediments, which contain the shells of marine animals, are compressed and buried under the ocean floor. Some of this carbon is released back to the atmosphere through volcanic eruptions and ocean vents or seeps that release gas (known as outgassing). If limestone rock is lifted to the surface of the planet, precipitation and lichen can dissolve it (weathering) and release carbon.

Be sure to point out the different time scales on which these flows take place. For example, the answer key (see Activity 7 webpage) to the Biological and Geological Carbon Cycle Diagram shows arrows from soil and ocean sediments down to fossil fuels. This is because the generation of new fossil fuels is an ongoing process. However, it is a process that takes place on a time scale of hundreds of millions of years. Contrast this to the burning of fossil fuels (represented by the arrow from fossil fuels to atmosphere), which began emitting large quantities of carbon in the 1800s and continues to grow.

LARRY KORHNAK, UNIVERSITY OF FLORIDA

Soils play an important role in the carbon cycle.

Systems Thinking Connection

If you have been using the Systems Enrichment Exercises (particularly the **Bathtub Dynamics** exercise from Activity 2), then your students are familiar with the systems concepts of ***stocks*** and ***flows.*** These terms are synonymous with the "pools" and "fluxes" discussed in this activity. As you work through the discussion questions with your students, be sure to emphasize the relationship of stocks and flows. If you didn't use this exercise earlier, you may wish to do so now.

Recall that there are two ways of reducing a stock: (1) reducing the flow into the stock and (2) increasing the flow out of the stock. Have students identify the flows into the stock of atmospheric carbon in this activity (e.g., respiration, burning). Then have them identify the flows out of the atmospheric stock of carbon (e.g., photosynthesis, dissolving into the ocean). Discuss ways to decrease flows of carbon into the atmosphere and increase flows of carbon out of the atmosphere.

ANNIE OXARART, UNIVERSITY OF FLORIDA

You can set up stations for this activity by printing the **Illustrated Station Cards** on the Activity 7 webpage.

Teaching This Content

This activity engages students by having them imagine they are carbon molecules traveling through different carbon pools. Students will likely enjoy and remember this part of the activity. However, it is equally important that students are given adequate time to apply and reflect upon the information they learn during the simulation. This is particularly important because the geological carbon cycle is not included in the simulation conducted in Part A. We strongly recommend that you complete both Part A and Part B of this activity so that students are exposed to the full carbon cycle and apply that information as they answer questions.

Getting Ready

The Activity 7 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section3/activity7).

If you would like to provide a short presentation on carbon and the carbon cycle, you can use the Introducing Carbon presentation on the Activity 7 webpage. If students need more background regarding biological or geological carbon cycle processes, see the Additional Resources for websites, readings, and videos.

Download and print one copy of the Illustrated Station Cards available on the Activity 7 webpage. You can also use the information provided on the Station Cards student page to create your own cards with images that reflect your local environment or surroundings.

Make copies of the Carbon Pathway and Mapping Carbon student pages (one for each student).

Set up eight stations, each with one die. The Station Cards should be visible from any place in the room, and the die should be placed on a table or desk. Students need enough space between classroom furniture to gather at each station and move between them.

Doing the Activity

Part A: The Biological Carbon Cycle

1. To introduce the topic of the carbon cycle, ask students to brainstorm what they already know about carbon and to provide examples of places carbon can be found. If needed, remind students that carbon is an element on the periodic table, is the fourth most abundant element, and can be found in different forms everywhere we look. You can use the Introducing Carbon presentation on the Activity 7 webpage to provide a brief overview of carbon and the carbon cycle. In addition, you might find these discussion questions helpful:

- Is there a fixed amount of carbon on the planet?
  Yes. Like water, there is a relatively constant amount of carbon on the planet. Also like water, carbon constantly moves through different states and pools.

- Do you have any carbon in you?
  Yes, in the carbohydrates, fats, proteins, enzymes, and tissues of your body.
- How is photosynthesis related to the carbon cycle?
  During photosynthesis, plants convert carbon dioxide and water into sugar in the presence of sunlight. This process moves carbon from the atmosphere to sugar in plant cells. Then, the sugars are either metabolized into energy in the form of ATP through the process of respiration or used as building blocks to form starch, cellulose, lignin, wood, leaves, or roots. Energy in the form of ATP is used to construct these complex molecules. This process, where carbon is removed from the atmosphere and stored in plant biomass, is known as sequestration.

2. Explain to students that they are about to become a carbon atom and move through the carbon cycle.

- The purpose of the activity is to help students better understand the variety of places that carbon can be found and how it moves from location to location.
- While carbon cycles geologically over millions of years, this part of the activity only focuses on the biological component of the carbon cycle that happens on a much shorter timeframe. In this cycle, carbon moves between different pools such as living organisms, land, water, and the atmosphere.
- Make sure students understand the terms *soil carbon*, *carbon pool*, *carbon flux, carbon cycle*, and *carbon sequestration*.
- Some students might get stuck in some parts of the carbon cycle or move back and forth between two carbon pools. Let students know in advance that this may happen, and that this mimics the real carbon cycle. If a student seems frustrated or upset by getting stuck, it is okay for them to move to another appropriate pool.

3. Give each student a copy of the Carbon Pathway student page and provide instructions for how they should use this worksheet to record their journey through the carbon cycle. Modeling what students should do when they arrive at their first station and how to move to subsequent stations helps the simulation move smoothly. Ask them to count off by eight and move to their first stations. Tell students they will complete eight rounds and record their journeys through the carbon cycle. If you have a small class, you may wish to have students complete additional rounds to increase chances that they will experience diverse outcomes and visit all the stations; which can lead to richer discussion after the activity.

- Students should write their first station on the first row in the table, roll the die, read the outcome from the card at that station, write down the next destination and the process that took them there, and move to that station.
- Even if some students end up staying at the same location after a roll of the die, they should write down the station name again and the process that led to them staying in place.

4. When everyone is finished, discuss the following questions as a class:

- Who visited the most pools? Who visited the least?
  Responses will vary. Some students may have visited all the stations, but many probably moved between the atmosphere and the forest or the ocean.
- Did anyone get stuck at one station or between two stations? Why do you think that happened?
  Point out that there are many different ways to enter and leave most carbon pools. The time carbon atoms spend in each pool varies. For example, some atoms might cycle very quickly between the atmosphere and forests through photosynthesis and respiration, while others may get sequestered in a tree for hundreds of years. This is built into the exercise through the number of options that keep the carbon molecule at the same station.

TEACHERS SAY ...

I loved this activity, especially to introduce the terms carbon pool, carbon sink, and carbon flux.

—Biology Teacher, Florida

JESSICA IRELAND, UNIVERSITY OF FLORIDA

Students work together to draw a carbon cycle that includes both biological and geological components.

Part B: The Full Carbon Cycle

1. Remind students that the simulation focused on the *biological* portion of the carbon cycle. Ask students if there are other places that carbon is stored and other ways that carbon moves?
Carbon is also stored in rocks, fossil fuels, and in sediments on the ocean floor and includes fluxes like weathering, compaction, combustion, and volcanic eruptions.

2. Introduce the geological portion of the carbon cycle, including how fossil fuels are created (see Additional Resources for more background information if needed). Carbon atoms in the geological portion of the cycle will be stuck for millions of years. Ask students to imagine how long it takes for carbon to move from ocean and terrestrial sediment to rock and fossils. Discuss how carbon is naturally released through weathering and volcanic eruptions in small amounts over very long periods of time. When fossil fuels are burned for energy, however, large amounts of carbon are released into the atmosphere in a very short time period.

3. Show the class the global carbon diagram (in Background Information and available for download on the Activity 6 webpage).

- Point out the major carbon pools and fluxes that are shown on the diagram. Ask students to list the carbon pools that they experienced during the simulation that are missing on this diagram (e.g., animals, wood products, marine life).
- Reinforce that the amount of carbon flowing through the biological portion of the cycle is fairly stable and that carbon is constantly moving from the atmosphere to plants or oceans and back to the atmosphere.
- Explain that human use of fossil fuels has added carbon to the atmosphere that previously had been locked in fossils for millions of years. This “old” carbon is changing the balance of carbon in the atmosphere and ocean. Carbon from fossil fuels contains a different isotope (i.e., a variation of a chemical element, differing in the number of

neutrons found in each atom) from that found in trees and other living things. This allows the atmospheric contribution from fossil fuels to be tracked.

4. Discuss potential effects of releasing additional carbon to the system.

5. Form groups of four to five students and give each student a copy of the Mapping Carbon student page. Instruct students to work together to draw a carbon cycle that includes both biological and geological components. When the groups finish, ask a representative from each group to share the group's diagram and responses to the questions on the student page.

- According to your diagram, what are the two ways carbon is removed from the atmosphere? List the pools and the fluxes.
  Forests through photosynthesis; oceans through dissolving.
- How might each of these pools be affected by increased amounts of carbon dioxide in the atmosphere?
  More atmospheric carbon dioxide allows plants to grow and develop more quickly. However, several other factors may influence the amount of forested land and forest health, such as land use changes, weather events, forest disturbances, as well as water and nutrient availability. An ocean with more carbon is more acidic; acidic oceans may alter coral reefs and other organisms.
- How could we change these pools to remove more carbon from the atmosphere? What might be the limitations of managing these pools in this way?
  Plant more trees; grow trees longer; increase carbon in the soil; make long-lasting products out of wood. These options may be limited by the following: amount of land on which trees will grow; wood will eventually decay; a warmer ocean will hold less carbon; a more acidic ocean will dissolve coral reefs and negatively impact marine life that use carbon to build shells and skeletons.
- What are the implications of removing the trees from a piece of land and developing it so that trees no longer dominate the landscape?
  The carbon from a forest could go into wood products or into the atmosphere if the forest is burned. Whichever way trees are removed, as long as they are not replanted, the result will be an area of land that will not be able to sequester as much carbon as it did when it was forested.
- Systems Reflection: How can thinking about the atmospheric greenhouse gases in terms of stocks and flows enable people to understand the system more clearly?
  Thinking in terms of stocks and flows can help people understand the climate change mitigation actions and policies in terms of the physical system. Efforts to reduce emissions from fossil fuels can be seen as attempts to reduce the flow of carbon into the atmospheric stock. Reforestation efforts can be seen as attempts to increase flow of carbon out of the atmospheric stock. Using both types of strategies concurrently provides the best chance of successfully addressing the challenge of climate change.

6. Summarize this activity by reminding students that the carbon cycle consists of both biological and geological pools and fluxes, which operate on different timescales. Through human activities, such as fossil fuel combustion and land development, carbon is being released from geological carbon pools. The carbon activities in this module focus on the ways trees and wood products can be used to remove carbon dioxide from the atmosphere or prevent future emissions. A variety of other classroom activities and programs can be used to explore other strategies for reducing atmospheric carbon dioxide. See the Additional Resources listed at the end of this activity.

TEACHERS SAY ...

I enjoyed this activity. The students were engaged and working well individually and with others.

—AP Environmental Science Teacher, Florida

Ask student groups to share their carbon cycle diagram and responses to the questions on the student page.

MARTHA MONROE, UNIVERSITY OF FLORIDA

Modifications

Younger students will benefit from "seeing" Part A of the activity in action, as you or another student model the instructions by rolling the die, selecting the flux, and moving to the next station.

Part B of this activity can be completed as a class discussion rather than in small groups, which can help you provide guidance and answer questions.

Enrichment

Ask students to research carbon-neutral energy sources that might replace fossil fuels. Why is using biomass, such as wood or corn, to produce energy considered carbon neutral? What factors determine neutrality? How could land-use changes impact biomass carbon neutrality?

Have students investigate how technology might be used to reduce carbon in the atmosphere. For example, people around the world are working to remove carbon from the atmosphere and store it underground and to reduce the amount of carbon that we add to the atmosphere by saving energy and reducing our dependence on fossil fuels. Ask students to write a report explaining one solution and to discuss its advantages and disadvantages.

Have a discussion with students on the relationship between the carbon cycle and other cycles that students are familiar with, such as water or nitrogen cycles. How are these cycles similar and how are they different? What are the key events in carbon cycle, water cycle, and nitrogen cycle?

Additional Resources

All about Carbon Dioxide, A Student's Guide to Global Climate Change
U.S. Environmental Protection Agency

http://epa.gov/climatestudents/basics/today/carbon-dioxide.html
This website contains a video describing the carbon cycle and how humans are changing its natural balance.

Global Warming: It's All about Carbon
Robert Krulwich, National Public Radio, 2007
http://www.npr.org/news/specials/climate/video/
As part of the Climate Connections Special Series, these five short videos teach basic concepts about carbon and its role in climate change.

GLOBE Carbon Cycle
University of New Hampshire
http://globecarboncycle.unh.edu/index.shtml
This education unit focuses on bringing cutting edge research and research techniques in the field of terrestrial ecosystem carbon cycling into secondary classrooms. It includes several activities to help students understand the carbon cycle, including a "choose your own adventure story."

Climate Science Info Zone
London Science Museum
http://www.sciencemuseum.org.uk/ClimateChanging/ClimateScienceInfoZone/ExploringEarthsclimate
This interactive website has a series of animations and videos related to the global climate, the carbon cycle, and climate change.

Steroids and Baseball
University Corporation for Atmospheric Research (UCAR)
https://www2.ucar.edu/atmosnews/attribution/steroids-baseball-climate-change
This two-minute video uses steroids in baseball as an analogy to carbon dioxide in climate and provides reflective comments on the purpose and value of the video.

The Carbon Cycle
Holli Riebeek, NASA's Earth Observatory
http://earthobservatory.nasa.gov/Features/CarbonCycle
The six sections of this online article provide a comprehensive look at the geologic carbon cycle, historical changes in the carbon cycle due to climate change, contemporary changes in the carbon cycle due to human activities, effects of these changes, and how the carbon cycle is studied. The article includes helpful photos, diagrams, graphs, and maps. A previous version of the article is available in PDF format at http://earthobservatory.nasa.gov/Features/CarbonCycle/carbon_cycle2001.pdf.

The Carbon Cycle: Forestry Never Looked So Cool
The Forest Foundation
http://www.calforestfoundation.org/pdf/carbon-poster.pdf
This poster (also available as a handout) provides a colorful depiction of the carbon cycle and highlights the role of forests and wood products.

The Carbon Cycle: What Goes Around Comes Around
John Harrison, Visionlearning, National Science Foundation, 2003
http://www.visionlearning.com/library/module_viewer.php?mid=95
This online module provides basic information about the carbon cycle including human influences. The module also includes an interactive quiz and section with links to other resources.

The Carbon Quilt
Carbon Visuals Ltd
www.carbonquilt.org
This website provides images and animations to help people better understand carbon emissions.

TEACHERS SAY …

This activity was one of my favorites and one of my students' favorites.
—Ecology Teacher, Virginia

CO_2 Carbon Pathway

NAME DATE

Instructions: Imagine you are a carbon atom in one of many places that carbon is found. Write your starting location on the first line, roll the die, and determine your next location. Follow the instructions for the number you roll to move to another station or stay where you are. What process was responsible for moving you from one carbon pool to another? Repeat this eight times and record in the table below what happens during each round. Make sure to record what happens, even if you have to stay at one station for more than one turn.

Round	Starting Location (Carbon Pool)	What happened? (Carbon Flux)	Ending Location (Carbon Pool)
Example	Atmosphere	Photosynthesis	Forest
1			
2			
3			
4			
5			
6			
7			
8			

CO_2 Station Cards (1 of 2)

Atmosphere

1. You continue to circulate through the atmosphere. **Stay at Atmosphere.**
2. You continue to circulate through the atmosphere. **Stay at Atmosphere.**
3. In a forest, a pine tree needle absorbs and uses carbon dioxide during photosynthesis. **Go to Forest.**
4. In a forest, a pine tree needle absorbs and uses carbon dioxide during photosynthesis. **Go to Forest.**
5. Near the East coast, you dissolve into the waters of the Atlantic Ocean. **Go to Surface Ocean.**
6. Near the East coast, you dissolve into the waters of the Atlantic Ocean. **Go to Surface Ocean.**

Wood Products

1. The lumber where you are sequestered is used to build a house. **Stay at Wood Products.**
2. The lumber where you are sequestered is used to build a house. **Stay at Wood Products.**
3. After many years, the lumber gets thrown in a pile of old wood and begins to rot and break down. **Go to Soil Carbon.**
4. You are eaten by termites. **Go to Animals.**
5. After many years, the lumber where you are sequestered gets burned for firewood. **Go to Atmosphere.**
6. After many years, the lumber where you are sequestered gets burned for firewood. **Go to Atmosphere.**

Forest

1. Through respiration, a tree uses your sugar molecule for energy. **Go to Atmosphere.**
2. The pinecone where you have been stored is eaten by an Eastern fox squirrel. **Go to Animals.**
3. You become sequestered in a tree's trunk. After several years, your tree gets cut down. **Go to Wood Products.**
4. You become sequestered in a tree's trunk. After several years, your tree gets cut down. **Go to Wood Products.**
5. You become sequestered in a tree root, which dies and decays. **Go to Soil Carbon.**
6. A fire moves through the forest and burns the tree where you have been stored. **Go to Atmosphere.**

Surface Ocean

1. Through wave action, you mix with air and come out of the water—leaving solution as carbon dioxide gas. **Go to Atmosphere.**
2. Through wave action, you mix with air and come out of the water—leaving solution as carbon dioxide gas. **Go to Atmosphere.**
3. You continue mixing in water near the surface of the ocean. **Stay at Surface Ocean.**
4. Water currents and ocean mixing send you deeper within the ocean. **Go to Deep Ocean.**
5. An algae plant takes you in during photosynthesis. **Go to Marine Life.**
6. An algae plant takes you in during photosynthesis. **Go to Marine Life.**

CO_2 Station Cards (2 of 2)

Soil Carbon

1. As the organic matter decomposes, you become carbon dioxide through soil respiration. **Go to Atmosphere.**
2. As the organic matter decomposes, you become carbon dioxide through soil respiration. **Go to Atmosphere.**
3. An insect eats the rotting material where you are located. **Go to Animal.**
4. An insect eats the rotting material where you are located. **Go to Animal.**
5. You become buried in layers of leaf litter and soil. **Stay at Soil Carbon.**
6. You become buried in layers of leaf litter and soil. **Stay at Soil Carbon.**

Deep Ocean

1. Ocean mixing and water currents send you toward the surface. **Go to Surface Ocean.**
2. Ocean mixing and water currents send you toward the surface. **Go to Surface Ocean.**
3. Ocean mixing and water currents send you toward the surface. **Go to Surface Ocean.**
4. Ocean mixing and water currents send you toward the surface. **Go to Surface Ocean.**
5. Water currents send you deeper within the ocean. **Stay at Deep Ocean.**
6. Water currents send you deeper within the ocean. **Stay at Deep Ocean.**

Animals

1. A bird eats you for dinner. **Stay at Animal.**
2. You are stored in animal fat cells. **Stay at Animal.**
3. You get released as carbon dioxide during respiration. **Go to Atmosphere.**
4. You get released as carbon dioxide during respiration. **Go to Atmosphere.**
5. When the animal produces waste, you find yourself on the forest floor in a pile of poop. **Go to Soil Carbon.**
6. The animal dies and begins to break down on the forest floor. **Go to Soil Carbon.**

Marine Life

1. You are eaten by tiny marine animal, called zooplankton. **Stay at Marine Life.**
2. You are eaten by tiny marine animal, called zooplankton. **Stay at Marine Life.**
3. You are exhaled through respiration. **Go to Surface Ocean.**
4. You are exhaled through respiration. **Go to Surface Ocean.**
5. The organism you are part of dies. You break down and sink through the waters of the Atlantic Ocean. **Go to Deep Ocean.**
6. The organism you are part of dies. You break down and sink through the waters of the Atlantic Ocean. **Go to Deep Ocean.**

Mapping Carbon (1 of 2)

NAME DATE

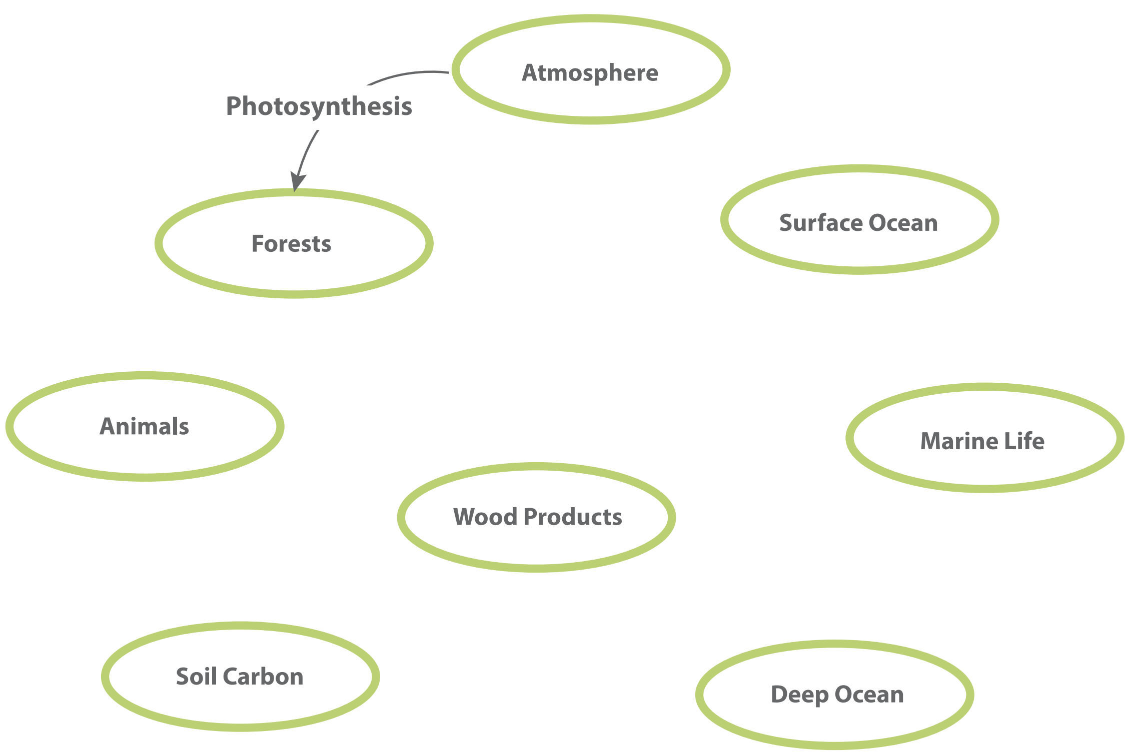
1. Use a large sheet of paper and markers to create a carbon cycle that combines the path that each group member experienced during the simulated carbon cycle. Use ovals or circles to represent the **carbon pools.** Use arrows to show how you moved from pool to pool, and label each arrow with the **carbon flux** that took you to the next pool.

   For example, one or more students in your group probably went from the atmosphere to the forest through photosynthesis. This means you would draw one oval labeled "atmosphere" and one oval labeled "forests." Then you would connect them with an arrow labeled "photosynthesis."

   Carbon fluxes that you may have experienced include:

Breaks Down	Leaves Solution	Respiration (Plant, Soil, Animal)
Burns (Combustion)	Ocean Mixing/Circulation	Sequestration
Dissolves	Photosynthesis	Waste Production
Eaten (Consumption)		

   Example Diagram for Biological Carbon Cycle



CO_2 Mapping Carbon (2 of 2)

NAME DATE

2. If needed, add additional arrows to represent any realistic pathways (fluxes) between pools that were not experienced by your group members. This diagram represents the **biological part** of the carbon cycle.

3. Add three new carbon pools to the bottom of your group diagram to represent the **geological part** of the carbon cycle: Fossil Fuels, Ocean Sediments, and Carbonate Rock / Limestone. Then use the following fluxes to describe how carbon moves between the new and existing carbon pools: Heat and Compression, Burning (Combustion), Volcanism (Outgassing), Weathering, Rock Formation, and Sinking.

4. According to your diagram, what are two ways carbon is removed from the atmosphere? List these fluxes and the pools.

5. How might each of these pools be affected by increased amounts of carbon dioxide in the atmosphere?

6. How could we change these pools and also remove more carbon from the atmosphere? What might be the limitations of managing these pools in this way?

7. What are the implications of developing a piece of land that used to be forested, so that trees no longer dominate the landscape?

8 Counting Carbon

Students measure trees near their school and calculate the amount of carbon stored in individual trees. Students compare the carbon sequestration potential for land-use types in their state, compare this to the amount of carbon released by human activities, and then discuss forests' ability to sequester atmospheric carbon.

CO_2

Subjects
Agriculture, Biology, Environmental Science, Mathematics

Skills
Analyzing, Calculating, Comparing and Contrasting, Identifying Relationships and Patterns, Inferring, Measuring

Materials
Student pages, answer keys, spreadsheet calculator (see Activity Webpage link below). Each student group will need a scientific calculator; measuring tape (or string and ruler); protractor or piece of cardboard; straw; string; weight (something heavier than a paper clip, for example washers); 100-meter measuring tape; and masking tape. Alternatively, you can use a DBH (diameter at breast height) tape and clinometer, if available.

Space Consideration
Outside area with enough trees so that each group can measure at least one tree.

Time Considerations
Two to three 50-minute periods and homework

Related Activities
Students should have an understanding of the carbon cycle (Activity 7). This activity can be followed with one of the activities that show additional ways forest managers can address climate change (Activities 5, 6, 11, and 12).

Research Connection
Scientists are exploring how much carbon is stored in forests and soils and modeling how to use growing forests and wood products to reduce atmospheric carbon dioxide.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section3/activity8

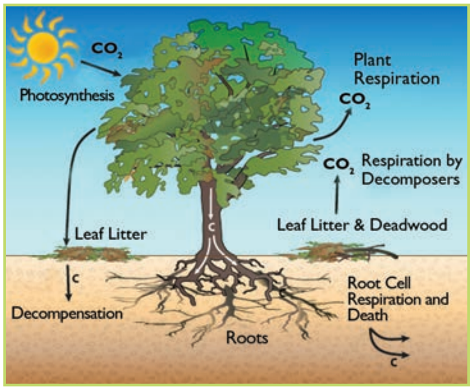
Objectives
By the end of this activity, students will be able to
- describe how forests help mitigate climate change; and
- compare the impact of sequestering carbon by different land-use types, such as pine forest, mixed forest, urban forest, cropland, and grassland.

Assessment
- Use student responses on the student pages to evaluate understanding.
- Ask students to write a summary that explains how forests can play a role in reducing atmospheric carbon dioxide and why understanding both carbon emissions and carbon sequestration is important.

Background

All plants and animals contain and use carbon to sustain life. The element carbon is found in the carbohydrates, fats, nucleic acids, and proteins of every biological life form. During ***photosynthesis***, trees use sunlight, water, and ***carbon dioxide*** to produce oxygen and glucose—a carbon-based sugar molecule. While some of the glucose is used during plant ***respiration***, some is stored in the trunk, branches, roots, and leaves as the tree grows. This stored carbon is removed from the ***atmosphere***. A tree's stored carbon can remain in the living tree or in cut wood for many years. Eventually, the stored carbon returns to the atmosphere when the wood decomposes, but this process can take a long time due to the tree's durable woody cells and tissues. For these reasons, forests store more carbon for longer time periods than other plants, such as corn or wheat, which have much shorter life spans and decompose more quickly.

Additional background information can be found in the **Section 3 Overview** and in **Activity 7**.



VALERIE MARTIN, TECHNICAL EDUCATION RESEARCH CENTERS

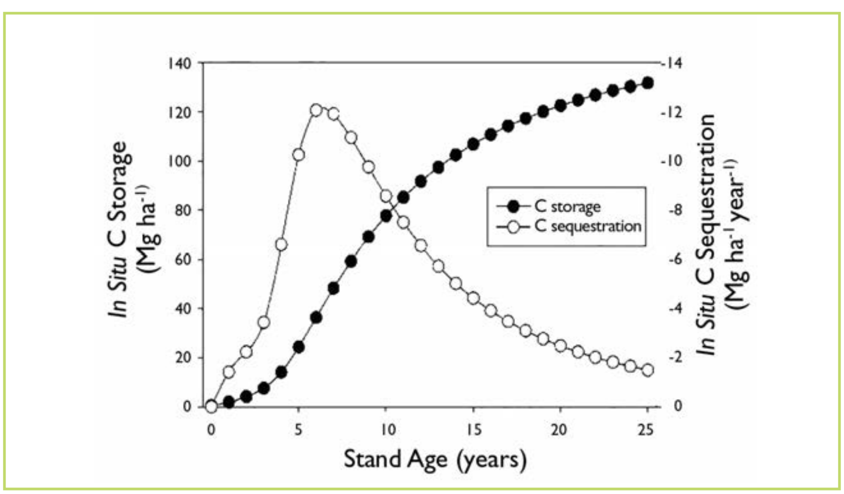
Trees play an important role in the carbon cycle by removing carbon from the atmosphere through photosynthesis. They also release carbon through respiration.

By absorbing and storing atmospheric carbon dioxide, forests are a vital part of the global ***carbon cycle***. And because scientists have linked increases in atmospheric carbon with increases in the global average temperature, forests are an important consideration in ***climate change*** as well. Estimating the amount of carbon that trees absorb, store, and release is key to understanding climate change and is one of the first steps in exploring how forests might be used to address climate change.

Calculating Carbon Storage

The amount of carbon that an individual tree can store depends on the size and ***species*** of the tree. To calculate ***carbon storage***, ***foresters*** and scientists first measure a tree's height and diameter. Within a sample plot, measurements are often taken for trees that are representative of the larger forest. The average of these data is then used to estimate the ***biomass*** within the larger forested area. To calculate tree diameter, a measuring tape is used to measure the tree's circumference. The circumference measurement is then divided by pi (π). Because diameter can vary with tree height, measurements are taken at a standard height from the ground—1.4 meters (4.5 feet). This height, called ***diameter at breast height*** (DBH), is high enough to avoid measuring the base of the tree (which often has a larger diameter than the rest of the tree trunk) and is low enough for most people to easily reach. The height of a tree can be measured in several ways. ***Clinometers*** provide efficient, accurate measurements and are commonly used by foresters. Clinometers measure angles from the point where a person is standing to the top and the bottom of a tree. Using geometry and trigonometry, these angles and the distance to the tree are used to calculate tree height. Together, tree height and diameter are used to estimate the tree's mass. When the mass of a living tree is measured, it is called the ***green weight*** and includes both the biomass of the tree and the moisture in the tree. The ***dry weight*** is calculated by subtracting the weight of the moisture, which is about 50 percent of a living tree. In general, the amount of carbon stored in an individual tree is about half of the tree's dry weight.

Figure 1. Carbon storage and carbon sequestration for a managed loblolly pine forest in Florida.



CARLOS GONZALEZ, UNIVERSITY OF FLORIDA

What is the Difference between Tree Carbon Storage and Carbon Sequestration?

Stored carbon is the amount of carbon that exists in a tree's leaves, wood, stem, roots, and bark at a particular point in time. Because older trees are larger than younger trees, they are able to store more carbon (see C storage line in figure 1). Knowing the amount of carbon stored in a tree and the tree's age allows us to calculate the rate of ***carbon sequestration***. This represents the net intake of carbon over a period of time. For example, net intake of carbon can be measured over the course of one year or the average net intake of carbon can be measured per year over the tree's lifespan. Because young, growing trees add biomass at a faster rate than older trees, they are sequestering carbon at a faster rate than older trees (see C sequestration line figure 1). Although the age at which maximum C sequestration occurs will vary with tree species, the general shape of the graph of this relationship is similar for all species.

Carbon Sequestration in Different Landscapes

From pine forests to agricultural lands, the southeastern United States supports many landscapes that sequester carbon. For the purpose of this activity, we divide landscapes in the Southeast into five major categories that represent common landscapes in the region: southern pine forest, mixed forest, urban forest, agricultural lands, and grasslands. Other ***ecosystems,*** such as marshes and wetlands, also store significant carbon in plant biomass and soils. While wetlands are not specifically addressed in this activity, you can find more information in the box on page 141 if you'd like to explore this topic with students.

One of the most abundant trees in the southeastern U.S. is loblolly pine (*Pinus taeda*). This species is often planted in privately owned pine ***plantations***. The majority of wood products, including lumber, plywood, and paper products produced in the Southeast are made from loblolly pine trees. Shortleaf pine (*P. echinata*), longleaf pine (*P. palustris*), and slash pine (*P. elliottii*) also grow in planted and ***naturally regenerated forests*** in this region. Together these pine species make up what many people call the "southern pine forests." This activity calculates overall area of southern pine forest for each state by combining the number of hectares for longleaf/slash pine and loblolly/shortleaf pine forest types, as determined by the U.S. Forest Service (USFS, 2013). Researchers have determined that on average, southern pine forests can sequester 3.80 tons of carbon per hectare per year (Binford et al., 2006). This sequestration rate is higher than the rates found in most other forested landscapes because southern pine trees grow quickly in the long, warm growing season.

In naturally regenerated forests, such as those in parks and other conserved lands, pines may grow with hardwood trees. These forests are generally referred to as "mixed forests" and differ from plantations in that they usually are not planted by people, not managed as intensively, and contain many species and trees of many different ages. Mixed forests can also be dominated by hardwood species, such as oak and hickory, or by wetland species, such as cypress and sweetgum. This activity calculates area of mixed forest for each state by subtracting the hectares of southern pine from the state's total hectares of forestland (USFS, 2013). The average sequestration rate for mixed forests in the Southeast is 1.90 tons of carbon per hectare per year (Turner et al., 1995). Due to the slower growing trees

Five Southeastern Landscapes

This activity allows students to compare the sequestration potential of five different landscapes commonly found in the Southeast.

Photos by: Larry Korhnak, University of Florida (pine, mixed, urban) • Florida Park Service (grassland) • Warren Gretz, National Renewable Energy Laboratory (cropland)

Carbon Storage and Sequestration in Wetlands

Wetland plant and tree species sequester and store carbon from the atmosphere, and similar to other ecosystems, this carbon is transferred to the soil through decaying plant matter. However, in many wetland environments, the soils are anaerobic (lacking oxygen), which slows the decomposition process. As a result, a large quantity of carbon is stored in wetland soils for a long period of time. This makes a wetland a powerful carbon sink. This activity focuses on carbon sequestration in forested and agricultural landscapes. While forested wetlands are included in the "mixed forest" acreage for each state, open wetlands and marshes are not accounted for in the state acreages provided in the activity. This is an important discussion point when interpreting the results for Part C of this activity, particularly in states with significant wetland areas along the coastline, such as Louisiana, North Carolina, and Florida. Developing wetlands usually means that the carbon stored in the soil goes into the atmosphere.

If you'd like to incorporate an activity extension to explore wetland carbon sequestration, the following resources are good starting points.

- **Protecting the Nation's Wetlands: Carbon Sequestration, Association of State Wetland Managers.** This webpage provides publications, resources, and answers to common questions about wetlands and carbon. http://www.aswm.org/wetland-science/wetlands-and-climate-change/carbon-sequestration
- **Sustainable Wetlands Adaptation and Mitigation Program.** You can find a range of publications and presentations about the role of wetlands in the carbon cycle and wetland-focused climate change adaptation and mitigation strategies. http://www.cifor.org/swamp/multimedia/presentations/
- **Wetlands International.** This website hosts a wealth of information about the importance of wetlands for carbon storage, climate change mitigation, biodiversity, water security, and more. http://www.wetlands.org/Whatwedo/Savingpeatlands/tabid/837/Default.aspx
- **Wetland Soil Carbon Sequestration, by Jim J. Wang and Syam K. Dodla.** This article describes research being conducted in Louisiana to better understand wetland soil carbon. https://www.lsuagcenter.com/en/communications/publications/agmag/Archive/2013/Spring/Wetland-Soil-Carbon-Sequestration.htm

TEACHERS SAY ...

My students enjoyed the second half of the activity where we discussed the amount of carbon used and sequestered. We actually ended up having a 45-minute discussion about what we can do to be proactive and sequester more carbon.

—AP Environmental Science Teacher, Florida

found in mixed forests and less-intensive management, this sequestration rate is half the rate of southern pine forests.

In addition to southern pine and mixed forests, trees located in urban forests sequester carbon and play a role in reducing atmospheric carbon. On average, urban forests sequester 0.80 tons of carbon per hectare per year (Norwak & Crane, 2002). The sequestration rate for urban forests is lower than for other forest types because of lower tree density.

The southeastern U.S. also contains agricultural lands, which are major economic resources for the region. Agricultural lands in the Southeast are used to grow fruits, vegetables, peanuts, and cotton. Similar to trees, crops sequester carbon. However, these plants do not sequester nearly as much carbon because they only live for one growing season. Croplands can sequester 0.10 tons of carbon per hectare per year (Morgan et al., 2010). This amount could be increased considerably, depending on management practices. For example, reducing soil tillage, maximizing water use by plants, and applying mulch to shade soil can increase the amount of carbon stored in cropland soils. Other practices, such as harvesting crops more frequently and planting specific types of cover crops during the nongrowing season, can increase carbon sequestration (Morgan et al., 2010).

Finally, the Southeast contains ***grassland*** areas that are used as pastures and rangelands. The grasses and shrubs within these landscapes sequester some atmospheric carbon each year, but because of their small size and short lifespan they do not sequester large quantities of carbon. On average, grasslands sequester 0.07 tons of carbon per hectare per year (Morgan et al., 2010). Similar to the croplands, the amount of carbon can be increased through ***best management practices***.

The state areas for urban forests, croplands, and grassland pastures that we use in this activity come from the USDA Economic Research Service's Report, *Major Uses of Land in the United States, 2007*. More information about each land use category is available online in the Economic Research Service Glossary located at http://www.ers.usda.gov/data-products/major-land-uses/glossary.aspx.

Systems Thinking Connection

IN THIS ACTIVITY, students learn to calculate how much carbon is stored in a single tree. The results may seem underwhelming compared to the enormous quantities of carbon released from ***fossil fuels***. If an individual makes an effort to reduce her ***carbon footprint***, she might decrease it by as much as 5 to 10 tons of carbon dioxide per year. This may seem insignificant when compared to the global carbon dioxide ***emissions*** of some 35 billion tons. As a result, some may be tempted to think that any effort to decrease an individual carbon footprint has little impact in the grand scheme of things.

The problem is this comparison involves two very different scales—the individual scale (personal carbon footprint) and the global scale (global carbon dioxide emissions). While there are certainly examples where an individual's actions under the right conditions have had significant impacts on much broader scales—consider Rosa Parks' refusal to give up her seat on a bus, which contributed to the Civil Rights movement—this is not the norm. Instead of judging the impact of an individual's actions based on a global scale, consider the cumulative impact of multiple individuals on the larger whole. When we decide to reduce our carbon footprint, we become a part of a global effort to reduce ***greenhouse gas emissions***. Individual actions *do matter* collectively when they are made by millions or billions of people. Encourage students to see their individual efforts to reduce their carbon footprints as part of a larger whole that can (and does) have significant impacts on atmospheric carbon levels.

Teaching This Content

This activity provides an opportunity for students to apply mathematics to real scenarios related to forests and climate change. Using their knowledge of geometry, students start their investigation at a very small scale by first exploring carbon storage in a tree near your school. Using calculation and unit conversion skills, students continue to increase the scale of their investigation so they can ultimately compare the state's carbon sequestration potential with the state's carbon emissions. Working through these calculations can help students better understand and explain the results, and assessing carbon information for their state may make the results more interesting and meaningful. The concepts in this activity help connect math and science—an important aspect of STEM (science, technology, engineering, and math) education. In particular, biology teachers might find the concepts useful for extending classroom discussions about carbon and the carbon cycle.

Getting Ready

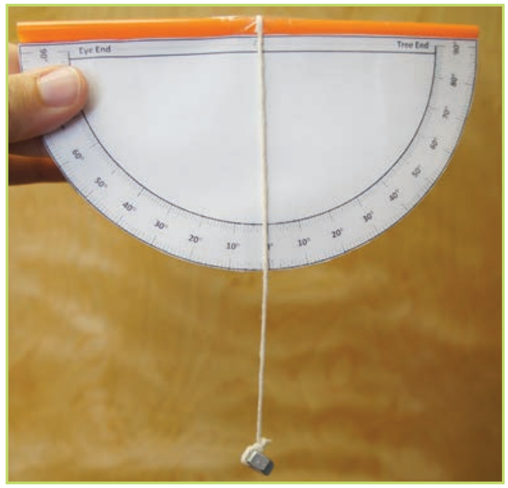
The Activity 8 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section3/activity8).

If you would like to provide a short presentation on carbon and the carbon cycle, you can use the Introducing Carbon presentation on the Activity 8 webpage.

This activity uses metric units; a version of the student pages using English units is available on the Activity 8 webpage.

This activity uses data specific to the southeastern U.S. for forest sequestration rates, state populations, and landscape areas.

If you would like to use data for other regions of the country, please see the



Regional Adaptations document on the Activity 8 webpage.

Make copies of the student pages (one per student).

There are two options for how students can calculate the carbon content of a tree.

- Option A: Students will use a tape measure, a clinometer, and a formula to calculate carbon content.
- Option B: Students will use a tape measure and a reference table to calculate carbon content.

See table 1 at the end of this activity to obtain current population and land use areas for your state. Students will use this information for calculations to complete the Carbon in Different Landscapes student page.

Option A—Making Clinometers to Measure Tree Height

For each group, you will need a protractor that is approximately 15 centimeters (cm) or 6 inches (in). Cut the image from the Protractor Template student page and tape it onto the protractor. If you do not have a protractor, you can easily tape the template onto a piece of cardboard that is cut to match the template shape. This template adjusts the measurements of the protractor so that students can read the angle directly from the protractor rather than completing calculations to obtain the correct angle.

You can easily make clinometers with the Protractor Template and a few additional materials.

Make sure the sighting straw is flush to the protractor so students don't poke their eyes when they gaze up to the treetops.

You will also need 1 straw, 1 weight (e.g., a washer or nut), and 20 cm (or 8 in) of string for each clinometer. Cut the straw to 15 cm (or 6 in) and tape it to the flat edge of the protractor. Tie one end of the string around the flat portion of the protractor at the center. On most protractors there is a hole to mark the center. Tie the other end of the string to the weight. When you hold the protractor with the straw on top and parallel to the floor, the string should cross the degrees portion of the template at the 0º line.

Assess the trees around your school to find ones that are suitable for students to measure. The students should be able to get close enough to the tree to put a measuring tape around its trunk 1.4 meters (4.5 feet) above the ground. They should also be able to stand far enough away to have a clear view of the top of the tree without straining their necks. The trees should be on relatively flat ground; the height equation provided in this activity cannot be used if the person's head is below the base of the tree or above the top of the tree when reading the clinometer. Count the number of suitable trees. One tree could work, but assigning several trees to each group is optimal so students can practice and improve their skills. Divide the class into groups based on the number of trees and time you have available.

Doing the Activity

Part A: Calculating the Amount of Carbon in a Tree

1. Make sure students understand the connection between carbon and climate change. Explain that carbon dioxide is a greenhouse gas, and scientists have linked increases in atmospheric carbon to increases in global average temperature.

2. Remind students that trees absorb carbon dioxide from the atmosphere during the process of photosynthesis. Some of this carbon dioxide is respired by the tree every minute of the day and night and goes back into the atmosphere as carbon dioxide and some of the carbon is stored in its growing roots, stems, and leaves. The process of photosynthesis enables a plant to remove or "sequester" carbon from the atmosphere.

3. Explain to students that they will be investigating the following questions:

- How much carbon is stored in an individual tree?
- How much carbon can be removed from the air or sequestered by a forest?
- How much carbon can be sequestered by other types of land use (e.g., agriculture)?
- Why is it important to know how much carbon a certain land use can sequester?
- How can we use this information to explore strategies for addressing climate change?

4. Split the class into groups based on the number of suitable trees. Explain to students that to measure carbon, they have to first measure the tree. Each group should measure at least one tree and determine how much carbon is stored there. Give each member of the group a copy of the Carbon in a Tree student page, walk students to the area you have selected, and assign each group to at least one tree.

5. Demonstrate how to take tree measurements and then provide enough time for students to measure their assigned trees.

- Circumference (Options A and B): Students measure the circumference of the tree trunk at approximately 1.4 meters (4.5 feet) from the ground. Explain why tree diameter measurements are taken at this height and how to calculate diameter (see Background section for explanation). One student should take the measuring tape (or string if measuring tape is not available) and wrap it around the trunk approximately 1.4 meters above the ground; other group members should record this value on the Carbon in a Tree student page. (If a string is used, the student will need to measure the string with a ruler to determine the circumference.)

MORGAN CHEEK, NORTH CAROLINA STATE UNIVERSITY

Teachers attending a workshop measure tree diameter and height.

- Height (Option A Only): Explain how to use the homemade clinometer and how these measurements can be used to calculate the height of the tree. Two students should walk away from the tree, until they can easily see the top of the tree, and measure the distance from that point to the tree. Standing at that point, one student should look through the straw to the top of the tree from the Eye End (90°) of the protractor. Once that student says he or she can see the top of the tree, another student should read the angle from the protractor template by noting the degree where the string crosses the protractor once the string stops moving. This is the "angle to top of tree" measurement (Θ_1). Another pair of students should then repeat the process while looking at the base of the tree from the same point. This is the "angle to base of tree" measurement (Θ_2). All data should be recorded on the Carbon in a Tree student page.

6. Back in the classroom, ask the students to sit in their groups and complete the rest of the Carbon in a Tree student page using their calculators. Make sure that if only one student was recording data that all group members write down the measurements on their student pages. You may need to remind them of the geometry that allows them to use the tangent of the angle to estimate the length of the far side of a right triangle. Also, review the equation used to determine how much carbon is stored in the tree. If you want students to practice using a spreadsheet to complete the calculations, you can download a template from the Activity 8 webpage.

7. Lead a class discussion about the carbon storage results that students calculated (Options A and B).

- What was the largest amount of carbon that was stored by a single tree? Was it clearly the biggest tree? What was the smallest amount of carbon stored by a tree?
- Draw a table on the board showing how much carbon was stored in the trees measured by each group. As a class, calculate the average amount of carbon stored by the sample of trees measured.
- Discuss the formula the students used by asking the following:
  –Besides diameter, what other factors might influence how much carbon a tree can absorb?
  Height, wood density, and whether the tree is evergreen or deciduous. Tree species and leaf area are often included in more complicated formulas.

Remind students to make sure they are looking through the straw at the Eye End of the protractor.

When calculating green weight, the constant in the equation accounts for the unit conversion between centimeters and meters. Therefore, students do not need to convert those measurement units to be the same.

TEACHERS SAY ...

The students really enjoyed the chance to measure the trees and be outside.

—Environmental Science Teacher, Arkansas

–Why are these factors not included in the formula?
For our purposes, we do not need to be so specific. We are looking at an average tree.

- For how long will the carbon in each of those trees be stored?
As long as the tree is alive or the wood exists in a product. Ask students to consider actions or events that are likely to kill trees in this area. Answers may include development, road widening, lightning, old age, and insects or disease.
- Where does the carbon go after it leaves the tree?
Some will be stored in soil; some will move to the atmosphere; some will be eaten and turned into energy for animals to use.
- How does carbon storage relate to growth? What does carbon content tell us about the age of the tree?
More carbon means an older tree.
- Does all of the carbon that is taken up by the tree end up in the tree as carbon storage? If not, where does some of the carbon go?
Some of the carbon is released during respiration. Total carbon uptake is not the same as carbon storage.

Part B: Exploring Carbon in a Pine Plantation

1. Using the data presented on the Carbon in Pines student page, have the students use the same formulas they used in Part A to calculate how much carbon is stored in a sample plot of a pine forest.

2. Have the students discuss the amounts of carbon stored in the pine forest that they calculated. Ask students why might this amount may be different from the amount they measured in the urban trees?
The faster a tree grows, the more carbon it sequesters, and pine forests are very efficient at sequestering carbon.

3. Present the idea of carbon sequestration and how it differs from carbon storage. Using the age of the sample forest, have the students calculate the sequestration rate for the pine forest. Ask students what this sequestration rate shows?
How quickly the trees uptake carbon and how efficient they are at absorbing atmospheric carbon.

4. Ask students what land uses sequester carbon other than the urban trees they measured and pine forests?
Cropland, grassland, and other forests can sequester carbon.

5. For homework, assign the Your Carbon Footprint student page. Students should come to the next class with an estimate of the amount of metric tons of carbon dioxide they emit in one year.

Part C: Comparing Carbon in Different Landscapes

1. Divide students into groups of five and have them discuss their responses to the homework assignment. How much do their responses differ? Why do they think their responses vary?

2. Re-introduce the concept of carbon sequestration and how it differs from the idea of carbon storage. Explain to students that they will be calculating the amount of carbon that can be sequestered by different land-use types in their state and then comparing that to the average amount of carbon that is emitted by the residential population in their state, based on the group average from the homework assignment.

3. Give each student in the group a copy of the Carbon in Different Landscapes student page. Also, give the students the data for your state from table 1 at the end of this activity. If you are adapting this activity for a state outside of the southeastern U.S., please see the Regional Adaptations document on the Activity 8 webpage.

4. Explain that each group will use its worksheet to calculate how much carbon, on average, the different land types in your state sequester in one year. Students will then compare this number to the amount of carbon emissions that would be produced if everyone in your state had, on average, a carbon footprint equal to the group's average footprint. Before the groups begin working, ask students to predict which of the five land uses they think will store the most carbon and why. What plants in each landscape are sequestering carbon? You can check the students' calculations by entering each student group's average carbon footprint into the answer key spreadsheet provided on the Activity 8 webpage. Be sure to find the row of the spreadsheet corresponding to your state.

5. When the groups finish, lead a discussion about different landscapes and carbon sequestration. You can use the information in the Carbon in Different Landscapes presentation to consider how your state's sequestration and emission results compare to the results from neighboring states.
Responses will vary by state and with emission data that students use for calculations.

- What carbon emissions are not included in the personal carbon footprint calculations that are part of the state's contribution to carbon in the atmosphere?
Energy used by schools, businesses, industries, and office buildings.
- Which landscape sequestered the most carbon? Was this different than the students' prediction? Why do students think that landscape sequestered the most carbon?
- What happens to the sequestered carbon in these landscapes? Is it mostly stored? In what ways might it be released back to the atmosphere?
- Could the all the landscapes combined sequester the carbon emitted by the state's population? If not, about what percent of the state emissions are sequestered?
- Should land in other states or in other parts of the world be used to sequester the carbon emitted in your state? Why or why not?
- If your state has an excess of sequestration potential, do you think other states should pay to have carbon sequestered in your state?
- If students decide to convert more land to the most efficient land use for sequestration, how do they convince landowners of this plan, and what should happen to the people who live and work in these areas? Is the idea of carbon sequestration within the state practical?
- Systems Reflection: If we cannot sequester all of the carbon emitted, what other actions may be necessary?
*In addition to sequestration, reducing the amount of carbon that we put into the atmosphere is an important consideration. This discussion can easily be extended to focus on the systems thinking skill of understanding the relationship between stocks and flows. Using the **Bathtub Dynamics** systems exercise on the Activity 2 webpage, you can demonstrate that reducing the stock of atmospheric carbon dioxide can occur through decreasing the inflow and increasing the outflow of carbon.*
- Systems Reflection: This activity suggests that people can compare their state's carbon emissions to their state's capacity to sequester that carbon in ecosystems. However, the stock of carbon is a global pool. From a systems perspective, which scale makes it easier to think of solutions: individual, community, state, nation, or planet? What are the advantages of considering the problem at each scale?
Encourage students to consider carbon on multiple scales. Fine scales (individual or local) may facilitate understanding about local actions that are necessary, while broad scales provide a sense of how our local actions fit into the global context.

6. Summarize this activity by reminding students that these concepts—amounts of carbon emitted through human activities

The **Carbon in Different Landscapes** presentation on the Activity 8 webpage provides emission and sequestration results for each southeastern state.

To continue exploring carbon sequestration, watch the Smithsonian Environmental Research Center's video, Ecosystems on the Edge: Forests and Climate Change.

and carbon sequestration potential of trees, soils, and plants—are a key aspect of climate change research. This type of information can be used in planning and policy creation at the local, state, regional, and national level. The pine forests of the southeastern U.S. represent a huge opportunity for reducing atmospheric carbon; however, sequestering carbon without making other societal changes can not alter climate change. Individuals, businesses, and industries must also make changes in the amounts of carbon emitted.

Modifications

This activity requires a fair amount of mathematical calculations. Teachers can adapt this activity for younger or less able students by using Option B, working through the calculations as a group, or by selecting the calculations they feel are most appropriate for students to complete and providing answers for the others. Pilot test teachers suggested this change would "allow more time to discuss the information without getting slowed down." If needed, you can skip the Carbon in Pines student page.

Enrichment

Have students investigate different carbon emissions reduction strategies and carbon sequestration strategies. Then ask students to develop, individually or in small groups, a climate change mitigation plan for your state and present it to the class. Should the carbon generated within each state be sequestered by the plants in that state? If not, who should be responsible for addressing the remaining emissions (other states, federal government, industry, other countries, etc.)?

Give students a scenario in which they are traveling on vacation with their family. Remind them that traveling by car, plane, or bus emits carbon. Tell them that some organizations will plant trees to offset the carbon emissions from various activities. People and businesses calculate how much carbon dioxide they produce during a particular activity and then pay the organization to plant enough trees to offset those emissions so that the activity is carbon neutral. Ask the students to write an essay or letter to their parents explaining the rationale behind planting trees to offset carbon emissions, the advantages and disadvantages of this strategy, and why they would or would not suggest it for a vacation trip.

Ask student to explore REDD+, the international program for Reducing Emissions from Deforestation and Forest Degradation and explain the rationale for this policy.

Additional Resources

Carbon in U.S. Forests, Online Tools
Forest Inventory and Analysis National Program, U.S. Forest Service
http://www.fia.fs.fed.us/Forest%20Carbon/default.asp
This webpage provides a fact sheet and graphics, as well as data tables for the estimations of carbon storage in U.S. forests.

Ecosystems on the Edge: Forests and Climate Change
Smithsonian Environmental Research Center
http://ecosystemsontheedge.org/forests-and-climate-change/
The Ecosystems on the Edge project aims to inform people about the effects of climate change on the planet and natural ecosystems. A 10-minute video shares information about carbon sequestration by forests and a research study that is tracking tree growth in Maryland.

Greg McPherson's Tree Carbon Calculator
EarthSky
http://earthsky.org/earth/greg-mcphersons-tree-carbon-calculator
In this podcast, scientist Greg McPherson talks about a tool he developed to help determine how much carbon a tree sequesters and the value of knowing this information.

How to Use a Clinometer Video
School of Forest Resources and Conservation, University of Florida
http://www.youtube.com/watch?v=q4LhwniXAJI
This video provides instructions for using a forestry clinometer to measure the height of a tree.

How to Measure Diameter at Breast Height Video
School of Forest Resources and Conservation, University of Florida
http://www.youtube.com/watch?v=B67QPJa2pbM
This video provides instructions for measuring a tree's diameter at breast height (DBH) using a DBH or logger's measuring tape.

National Tree Benefit Calculator
Casey Trees and Davey Tree Expert Co.
http://treebenefits.com/calculator/
Based on U.S. Forest Service's i-Tree tools, this online calculator provides annual data about the environmental and economic value of street-side trees. After entering the tree's location, species, and size, users receive data regarding the tree's environmental and economic value.

Urban Forests and Climate Change
U.S. Forest Service
www.fs.fed.us/ccrc/topics/urban-forests/ctcc/
This webpage provides downloadable software that allows users to enter information on climate region and tree size or age to calculate the amount of carbon dioxide stored in the tree over time, the amount of carbon dioxide sequestered in the past year, and the dry weight of the aboveground biomass.

What Types of Urban Greenspace Are Better for Carbon Dioxide Sequestration?
University of Florida, Cooperative Extension Service
http://edis.ifas.ufl.edu/uw324
This short fact sheet provides a chart that compares residential, natural, and commercial land uses for carbon sequestration by trees and grass in several cities in Florida.

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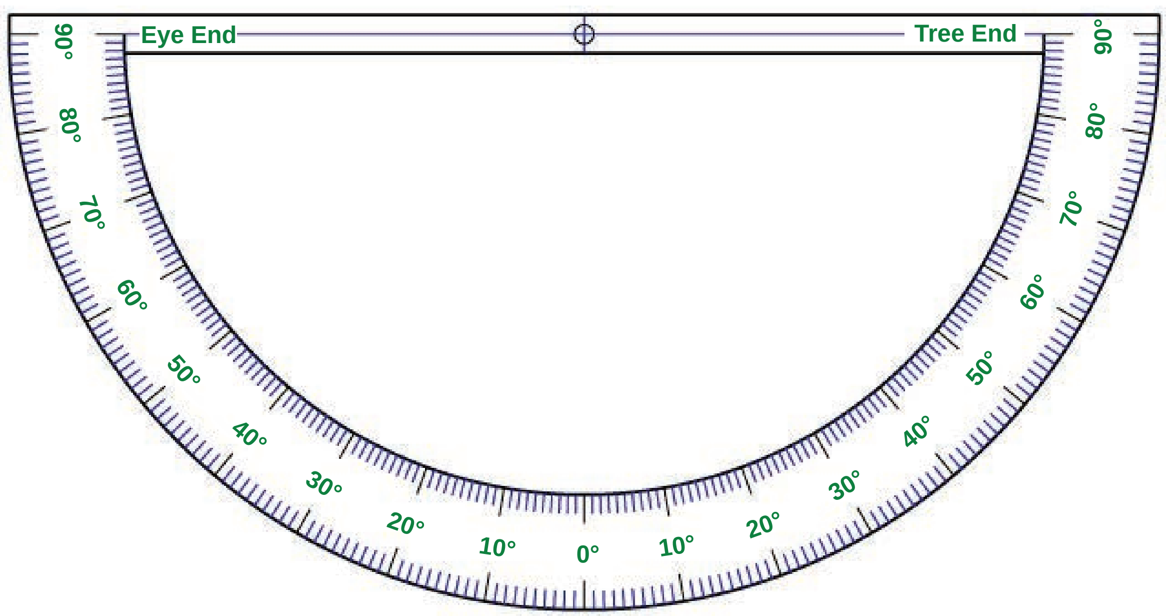
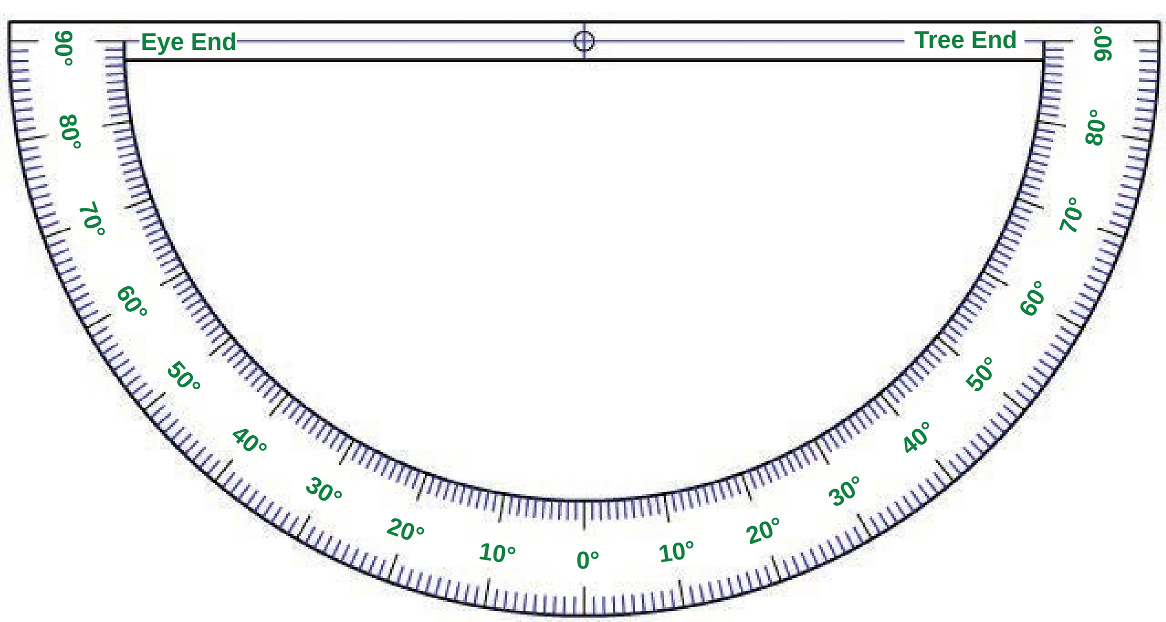
The National Tree Benefit Calculator allows students to enter a tree's location, size, and type of species, and then provides data on that tree's environmental and economic value.

STUDENT PAGE

CO_2 Protractor Template

Cut out this template to tape on your protractor. This template adjusts the measurements of the protractor so that students can read the angle directly from the protractor rather than completing calculations to obtain the correct angle.





CO_2 Carbon in a Tree (Option A) (1 of 3)

NAME: GROUP MEMBERS:

First, you will measure the circumference and height of at least one tree near your school. You will then use the data to calculate the amount of carbon stored in each tree.

Measuring Tree Diameter

1. Use your measuring tape to measure the circumference of the tree. Be sure to measure the circumference approximately 1.4 meters (about 4.5 feet) above the ground. Record the circumference in centimeters in Data Table 1.

2. Next, use the equation $d = c \div \pi$ to calculate the diameter of the tree (where d = diameter; c = circumference; and $\pi = 3.14$). Record tree diameter in Data Table 1.

Data Table 1

Tree	c circumference (cm)	d diameter (cm)
1		
2		
3		
4		
5		

Measuring Tree Height

1. Stand far enough from the base of the tree to see the top. Measure the distance between you and the tree and record it in Data Table 2. Hold the protractor with the Tree End toward the tree and look through the straw. Find the top of the tree and have another group member read the angle at which the string crosses the protractor (θ_1). Make sure your fingers are not blocking the string from moving freely. Record the angle in Data Table 2. To measure the angle to the bottom of the tree, look through the straw and find the base of the tree. Have a group member read the angle at which the string crosses the protractor (θ_2). Record the angle in Data Table 2.

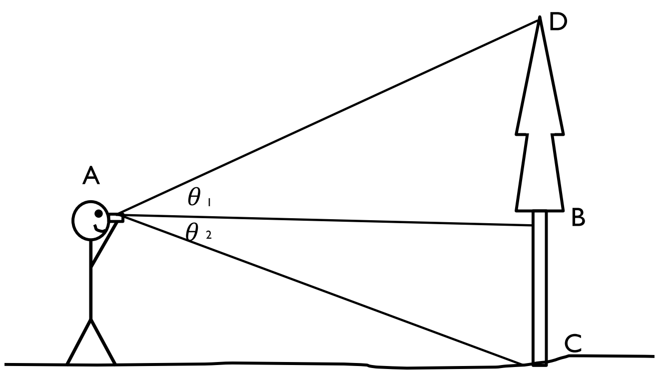
Data Table 2

Tree	θ_1 Angle to top of tree	θ_2 Angle to base of tree	AB Distance from person to tree (m)
1			
2			
3			
4			
5			

Are you standing on a slope while using the clinometer? If your head is below the base of the tree or above the top of the tree, find a new tree to measure! The equation provided for calculating tree height cannot be used in these situations.

CO_2 Carbon in a Tree (Option A) (2 of 3)

1. Next, use the following diagram and equations to calculate the height of each tree, noting that Θ_1 is the angle to the top of the tree and Θ_2 is the angle to the base of the tree. The tangent of the angle is expressed as tan. The distance between you and the tree is expressed as AB. Record your results in Data Table 3.



$\tan\Theta_1 = \frac{DB}{AB}$ $\quad$ $DB = AB \tan\Theta_1$

$\tan\Theta_2 = \frac{BC}{AB}$ $\quad$ $BC = AB \tan\Theta_2$

Total tree height = $DB + BC = AB(\tan\Theta_1 + \tan\Theta_2)$

Data Table 3

Tree	$\tan\Theta_1$	$\tan\Theta_2$	$DB = AB(\tan\Theta_1)$	$BC = AB(\tan\Theta_2)$	Tree Height (h) in meters (m) $h = DB + BC$ $h = AB(\tan\Theta_1) + AB(\tan\Theta_2)$
1					
2					
3					
4					
5					

Calculating Carbon Storage (adapted from Trees for the Future, 2007)

1. *Calculating Green Weight (GW)*

   The green weight of a tree is an estimate of the mass of the tree when it is alive. This estimate includes all of the wood content and any moisture in the tree. Because the moisture in the tree can be up to hundreds of liters, the green weight can be quite large.

   As you can imagine, weighing a live tree and keeping it alive is not feasible! For this reason, foresters use a set of formulas to estimate green weight. These equations are based on real data—foresters cut and weighed trees and then analyzed the data to develop formulas to fit the data. The percentage of moisture in a tree varies by tree species; therefore, specific formulas have been developed for different tree species.

CO_2 Carbon in a Tree (Option A) (3 of 3)

The equations used here are an "average" for trees in the Southeast and allow you to calculate the above-ground green weight of a tree based on the tree's diameter and height. To find the green weight, insert the values you obtained for diameter (cm) and height (m) into the appropriate equation and record your answers in kilograms (kg) in Data Table 4.

For trees with diameter < 28cm: $GW = 0.0577 \times d^2 \times h$

For trees with diameter > 28cm: $GW = 0.0346 \times d^2 \times h$

The constant in the equation accounts for the unit conversion between centimeters and meters; therefore, you do not need to first convert those measurement units to be the same.

2. *Calculating Dry Weight (DW)*

   Dry weight represents the mass of the wood in the tree when dried in an oven so the moisture is removed. On average, experiments have shown that a tree's dry weight is about 50% of its green weight. Therefore, to find the dry weight, you just need to multiply green weight (GW) by 50%. Complete this equation for each tree you measured, and record your answers in Data Table 4.

   $DW = GW \times 0.5$

3. *Calculating Carbon Storage (C)*

   Carbon storage is the amount of carbon that is within the wood of the tree. This is the total amount of carbon that is captured from the atmosphere during photosynthesis as well as the amount of carbon sequestered by the tree. From experiments, scientists have found that about 50% of a tree's dry weight is carbon. To find carbon storage, multiply dry weight (DW) by 50%. Complete this equation for each tree you measured, and record your answers in Data Table 4.

   $C = DW \times 0.5$

Data Table 4

Tree	**Green Weight (GW, kg)** d < 28cm: $GW = 0.0577 \times d^2 \times h$ d > 28cm: $GW = 0.0346 \times d^2 \times h$	**Dry Weight (DW, kg)** $DW = GW \times 0.5$	**Carbon content (C, kg)** $C = DW \times 0.5$
1			
2			
3			
4			
5			

CO_2 Carbon in a Tree (Option B)

NAME: GROUP MEMBERS:

First, you will measure the circumference of at least one tree near your school. You will then use the data to calculate the amount of carbon stored in each tree.

Measuring Tree Diameter

1. Use your measuring tape to measure the circumference of the tree. Be sure to measure the circumference approximately 1.4 meters (about 4.5 feet) above the ground. Record the circumference in centimeters in Data Table 1.

2. Next, use the equation $d = c \div \pi$ to calculate the diameter of the tree (where d = diameter; c = circumference; and $\pi = 3.14$). Record tree diameter in Data Table 1.

Data Table 1

Tree	c circumference (cm)	d diameter (cm)
1		
2		
3		
4		
5		

Calculating Carbon

1. The table below provides carbon content values for trees, based on their diameter values. This table is specific to urban trees in a developed area. The values were calculated in a study conducted in Escambia County, in Florida's panhandle (Escobedo et al., 2009). We can use this information to get a general idea of the amount of carbon in a tree that falls within a certain diameter range. Using the table below, match the diameter you calculated for your tree with the diameter in the left column. Find the carbon storage capacity of the tree and record in Data Table 2.

Diameter Range (cm)	Carbon Content per Tree (kg)
0–15	22
16–30	250
31–45	604
46–60	1,169
61–76	2,664
77+	15,034

Data Table 2

Tree	Carbon content (kg)
1	
2	
3	
4	
5	

CO_2 Carbon in Pines (1 of 2)

NAME:

The southeastern United States is home to many different species of pine trees, specifically: loblolly, slash, longleaf, and shortleaf pines. Pine forests are important for many reasons. They provide wildlife habitat, recreation, and clean water, and as you have learned, the trees store carbon as they grow. In the Southeast, pine trees are commonly grown in plantations to provide wood products, such as timber and paper.

Foresters and scientists measure pine trees with a method similar to the one you used on the trees in your schoolyard. Using this information they can determine how much carbon is stored in a certain area of the forest. The trees that are grown on a plantation are usually similar in size and age. This allows foresters to measure a small sample of trees and then use those numbers to estimate carbon storage for the entire area.

To estimate how much carbon typically exists in one hectare of pine forest in the southeastern United States, you will use data collected by high school students during a field trip to a pine forest sample plot in North Central Florida.

In a plot that measures 1/40th of a hectare, the students measured ten trees and found that the trees have an average diameter of 25.7 centimeters and an average height of 32.5 meters. Because the trees in this area are generally the same species, age, and size, we can use their average data to estimate the amount of carbon contained within one hectare of this forest.

JESSICA IRELAND, UNIVERSITY OF FLORIDA

Students measure tree height and diameter on a sample plot of slash pine trees in a forest in North Central Florida.

CO_2 Carbon in Pines (2 of 2)

Complete the calculations below, where d = diameter; h = height; GW = green weight; and DW = dry weight.

1. Green Weight (GW) = $0.0577 \times d^2 \times h$ GW = ____________ kg/tree

2. Dry Weight (DW) = GW × 0.5 DW = ______________ kg/tree

3. Carbon (C) = DW × 0.5 Carbon content = ___________ kg C/tree

4. Total carbon content of plot = carbon content per tree × 10 trees

   Total carbon content of plot = _____________ kg C in 1/40th hectare plot

5. Total carbon content of 1 hectare = total carbon in plot × 40

   Total carbon in 1 hectare = ___________ kg C/hectare

This final number illustrates the total carbon stored in one hectare of pine plantation where the students took measurements. However, this is not the same as the amount of carbon that the trees sequestered in one year of growth. Carbon sequestration is the net intake of carbon by the tree over a period of time. In this case, the forest where students sampled is 25 years old. Assume that trees sequestered carbon at the same rate during each year it lived, and use the equation below to determine what rate carbon is sequestered by the forest annually.

Total carbon in 1 hectare ÷ 25 years = Carbon sequestration rate

6. Carbon sequestration rate = _________________ kg C/ hectare /year

CO_2 Your Carbon Footprint

NAME:

The carbon footprint of a person is the total amount of carbon emitted based on his or her daily actions and choices. A carbon footprint is measured based on factors such as fossil fuel consumption, food consumption, goods and services bought, as well as housing conditions. The Nature Conservancy has an interactive site where you can answer questions to measure your own carbon footprint. This website allows you to see how much carbon dioxide (CO_2) you emit per year measured in metric tons. Follow the outline below in order to obtain your own personal footprint. You might need to ask your parents to provide some information so you can accurately complete the questions in the carbon footprint calculator.

1. Go to the website http://www.nature.org/greenliving/carboncalculator/index.htm.

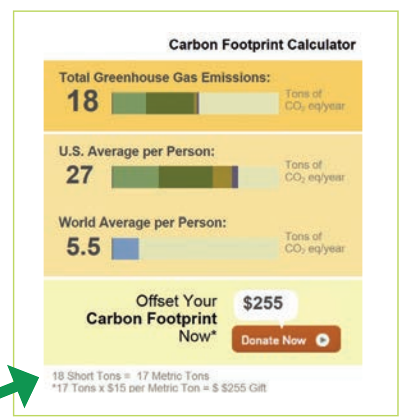
2. Read the instructions and select "For Me Only" because this exercise is for measuring your personal emissions. Use the survey to answer background questions as well as questions about household vehicles, home energy, and waste disposal. Answer the questions based on your personal or family lifestyle.

3. The second part of the survey estimates carbon output associated with your home energy usage. In the United States, most CO_2 is from energy generation. This part of the survey measures how much CO_2 you are responsible for emitting as a result of using electricity in your house. Answer the questions as accurately as possible.

4. The third part of the survey is based on your fossil fuel consumption associated with travel.

5. The fourth part of the survey evaluates how your choice of food and your diet affects your carbon emissions. Depending on the type of food, the amount of meat, and where you buy your food, your emissions will vary.

6. The final part of the quiz evaluates your level of waste and the impact that recycling has on it. If you recycle on a regular basis, your carbon estimate will be smaller. This is because recycled material requires less carbon to process than extracting and processing new resources.



7. Upon completing the survey, the results will display how much CO_2 you produce yearly as a result of your choices. Your results will be given in short tons. In a smaller font, at the bottom of the results box, you'll see your results in metric tons. This is the number you should record in step 8. You will see your results compared to the national average, and you will be provided with options to decrease your carbon emissions.

8. Record your results: ____________________ metric tons of CO_2 per year.

9. Are the results surprising to you? Why or why not?

10. What variable do you think was most responsible for your CO_2 emission rate? ________________________

CO_2 Carbon in Different Landscapes (1 of 3)

NAME: GROUP MEMBERS:

For this worksheet, carbon emissions and sequestration will be measured in metric tons. For shorthand, metric tons are referred to as tons.

Carbon Emissions

Using the data from the Your Carbon Footprint assignment, find the average carbon emissions for your group in tons of carbon dioxide (CO_2).

____
Average CO_2 emissions of group (tons/year)

1. Because most sequestration rates are calculated in terms of carbon and not in carbon dioxide, convert your tons of carbon dioxide to tons of carbon. To do this you'll use the formula below. Multiplying by 12/44 (or 0.2727) removes the weight of the two oxygen atoms (16 each) from the total weight of each carbon dioxide molecule (44).

______________________________ x $\frac{12}{44}$ = ______________________________
Average CO_2 emissions of group (tons/year) Average C emissions of group (tons/year)

2. If everyone in your state acted the way you do, find the total emissions for your state. To do this, take your group's average carbon emissions and multiply by the population of that state. Your teacher will give you this information.

________________________ x ________________ = __________________________
Average emissions of C (tons/year) State population Total C emissions of state (tons/year)

CO_2 Carbon in Different Landscapes (2 of 3)

Carbon Sequestration

Since there are multiple land uses that can sequester carbon, you need to determine the relative abilities of each of these land uses in carbon sequestration: southern pine forest, mixed forest, cropland, grassland, and urban forest. Complete the chart below, using land area provided by your teacher.

Land Use Type	Area in State (hectares [ha], in thousands)	Multiply	Carbon Sequestration Rate (tons/ha/yr)	Equals	Amount of Carbon Sequestered (tons/yr)
Southern Pine Forest (Binford et al., 2006)		×	3.80	=	
Mixed Forest (Turner et al., 1995)		×	1.90	=	
Urban Forest (Norwak & Crane, 2002)		×	0.80	=	
Cropland (Morgan et al., 2010)		×	0.10	=	
Rangeland/Grassland (Morgan et al., 2010)		×	0.07	=	

1. Total the amount of carbon that is sequestered by your state's land uses by adding the total carbon sequestered from the last column in the table.

____
Total C sequestered in state (tons/year)

Comparison Emissions and Sequestration

1. Is there a deficit in carbon sequestration or an excess of potential in your state? To find out if your state has the ability to sequester all of the carbon that it emits on average, subtract the total carbon sequestered in step 3 from the total carbon emitted by the population in step 2.

_______________________ – _______________________ = _______________________
Total C emissions of state (tons/year) Total C sequestered in state (tons/year) Difference (tons/year)

2. If your answer to step 4 is negative, that means that your state is not in a deficit and that on average the state has the ability to sequester all of the carbon that it emits. What factors might make a state able to sequester the carbon emitted by the population?

CO_2 Carbon in Different Landscapes (3 of 3)

3. If the answer to step 4 is positive, your state is in a deficit and cannot sequester the total carbon emitted, what could be done to increase the amount of carbon sequestered in your state?

4. If your state is in a deficit and any neighboring states are not, would you recommend that your state rely on the land uses of another state to sequester your carbon? Is it fair to the population of the other state to be responsible for your carbon emissions? Should you pay that state to sequester your carbon?

Table 1. Population and Land Use Areas for Southeastern States

States	Population[1]	Southern Pine[2]	Mixed Forest[3]	Cropland[4]	Rangeland[4]	Urban Area[4]
	(thousands)	(in thousands of hectares)				
Alabama	4,779	3,865	5,393	1,256	1,069	461
Arkansas	2,915	2,251	5,338	3,334	1,333	238
Florida	18,801	2,993	4,025	1,117	2,249	1,640
Georgia	9,687	4,475	5,548	1,869	523	997
Kentucky	4,339	79	4,969	3,084	1,423	323
Louisiana	4,533	2,326	3,559	1,795	753	440
Mississippi	2,967	3,237	4,671	2,249	832	246
North Carolina	9,535	2,325	5,197	1,960	498	954
Oklahoma	3,751	446	4,671	5,196	7,571	298
South Carolina	4,625	2,455	2,855	810	322	498
Tennessee	6,346	379	5,263	2,436	847	645
Texas	25,145	2,144	23,118	13,806	41,171	1,880
Virginia	8,001	1,187	5,250	1,316	997	629

[1] United States Census Bureau, 2012
[2] United States Forest Service, 2013 (area given is longleaf/slash pine and loblolly/shortleaf pine forest types)
[3] United States Forest Service, 2013 (area given is the total forestland minus the longleaf/slash pine and loblolly/shortleaf pine forest types)
[4] United States Department of Agriculture, 2012 (land use definitions found in the Economic Research Service Glossary at http://www.ers.usda.gov/data-products/major-land-uses/glossary.aspx)

SECTION 4

Life Cycle Assessment

Consumer choices can play a role in reducing carbon emissions.

MANY PEOPLE HAVE A HUGE DIVERSITY OF GOODS AND SERVICES conveniently available to them. This makes it challenging for them to choose products that have less impact on the environment. Most of us think that the life of a product begins when we open the box and ends when we throw it away. However, when scientists, engineers, and marketing professionals refer to the "life cycle" of a product, they include everything from the acquisition of the raw materials through use and finally disposal of those materials. ***Life cycle assessments*** provide key information that help people understand how human activities affect environmental and social ***systems***. By understanding the life cycles of products, consumers can compare the environmental impacts of various products and choose those that support their values and beliefs. In particular, consumers can choose products that ***mitigate climate change*** because they

- are produced using fewer ***greenhouse gases*** in production, shipping, and use;
- ***sequester carbon*** (wood products for example);
- can be reused or ***recycled*** instead of thrown away.

Life Cycle Assessment

Life cycle assessment involves taking a detailed look at the entire life cycle of a good or service. To do this, scientists define a product system and look at the material and energy flows into and out of that system during each step in the life cycle. Consider something as common as a cell phone. The circuits within your cell phone require an assortment of metals, including copper, gold, and lead, as well as lesser known metals such as tantalum and beryllium. The battery contains still more metals—usually nickel or lithium. These metals are mined and collected from all around the world. Then there's the casing and the screen for the phone, both usually made of synthetic plastics or resins. These materials must be transformed from their natural state so they can be used to manufacture the various parts of the phone. Then those parts must be assembled. Energy and additional materials are used at each step of the manufacturing process. In short, a world of activity has taken place before our new phone ever reaches us. Likewise, the phone's impact does not end when we throw it away. The materials within the phone continue to have both

A cell phone is a commonly used product with a very complex life cycle. Metals, plastics, resins, and other materials are all transformed to complete the manufacturing step of the life cycle!

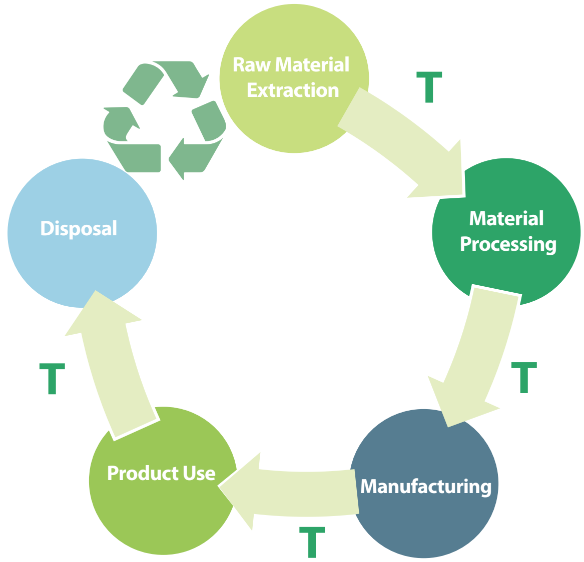


Figure 1. Stages of the life cycle of a service or product are shown in this figure, with transportation from one stage to another designated by the letter T. The recycling arrows between Disposal and Raw Material Extraction indicate that some products may be recycled to make other products.

ecological and economic impacts. Some of those materials are toxic, and many are quite valuable if they can be recycled and used in other electronic products. Those materials that are not recycled typically end up in landfills.

Figure 1 illustrates the generalized steps of a product's life cycle. The arrows represent energy and resources used to transport materials from one step to another. Energy and materials that flow into the product system at each stage are called resources. Materials flowing out of the system are called ***emissions***. Life cycle assessment looks at the environmental effects of the resource use and of the emissions created.

The three activities in this section allow students to learn about the environmental impact of products and to consider how the decisions and actions of consumers can affect local and global systems.

ACTIVITY 9: The Real Cost introduces the hidden impacts of everyday products that students might buy, such as t-shirts, fruit, and a bottle of water. Through a simulated shopping experience, students become consumers and choose which of two similar products to buy. This exercise is done twice—before and after reading information about the environmental ***externalities*** of those products. This activity enables students to explore the social and ethical implications of product cost and quality.

ACTIVITY 10: Adventures in Life Cycle Assessment is an opportunity for students to investigate actual life cycle data from the National Renewable Energy Laboratory (NREL) U.S. Life-Cycle Inventory Database. This activity asks students to imagine that their school has asked them to decide which type of outdoor dining furniture should be purchased for a new cafeteria patio—a product that will contribute the least to climate change. Using a three-act play or group presentations, students uncover life cycle data for the ***greenhouse gas emissions*** of pine, aluminum, and plastic resin furniture. An optional enrichment exercise includes a tutorial that walks advanced students through the process of using the NREL database to create a life cycle assessment for products of their choice.

ACTIVITY 11: Life Cycle Assessment Debate uses a classroom debate to help students consider advantages and disadvantages of similar products. The experience helps them consider the key questions that can be asked about any product when considering whether or not to buy it. Recognizing that life cycle data are not readily available and that answers are not always easy to find, the outcome of this activity is a blueprint that students can use to help guide their consumer decisions.

Potential Areas of Confusion

There are several topics in this section that may be sources of confusion for students, based on their assumptions, prior experiences, or existing knowledge. You may be able to use questions to uncover this confusion and steer students toward the clarifications provided in the table.

Assumption or Confusion	More Adequate Conception
Recycled is another word for renewable resources.	***Recycled*** means that the product was returned to a pre-production state and used to make new products. ***Renewable*** means the original ingredients of the product are capable of reproducing or reforming, such as deer, trees, and soil. Resources that are not renewable are in limited supply, such as some minerals. Plastic bottles made from petroleum are recyclable but are not from a renewable resource. Many people consider ***nonrenewable resources*** to be the highest priority for recycling, so that we can continue to use these resources in the future.
Life cycle assessment is easy to do on any product.	The more ingredients a product has, the more difficult it is to determine the impact of every ingredient. Everyday products, such as cell phones, are composed of dozens of different materials and parts, each of which can have a separate path of production. Further complicating matters is the fact that some production processes are proprietary information and not available to curious consumers. While everything has some level of environmental impact, it is often difficult to know what it is.
The way a product is produced represents the largest impact of a product's life cycle.	The materials and energy needed to make a product may represent larger impacts than other stages of the life cycle, but this is not always the case. For example, with cotton clothing, the amount of energy used for washing (in hot water) and drying the clothing over the course of its lifetime can be more than the energy used during production.
Life cycle assessment can tell us which product is better.	Determining "better" is often difficult because products have different types of impacts. Which is worse: Water pollution or climate change? Using a nonrenewable feedstock for a product that lasts 50 years or using disposable and renewable material? Such questions are the essence of interesting debate and are often decided with values, not science. In addition, the "best" answer may vary in different parts of the country or in different contexts.
Similar products are made the same way.	People can tell the difference between different brands of ice cream because they have different ingredients and may be made through different processes. The same may be true for various brands of anything. This makes life cycle analysis difficult, since brands may be produced differently.

By analyzing life cycles of comparable products, one can determine if there are critical environmental impacts that should be considered prior to making a purchase.

Key Concepts in This Section

- Negative externalities often impact the environment and society; their costs may be borne by everyone or they may be ignored.
- Negative externalities can occur at any point in a product's life cycle—not just when the product is made or used.
- Life cycle impacts include more than the ingredients and distance traveled. How the product is used and maintained (dry clean or wash; hang dry or use an electric drier; dispose or repair) and whether the product can be recycled or composted can vary.
- By analyzing life cycles of comparable products, one can determine if there are critical environmental impacts that should be considered prior to making a purchase.
- Consumers can influence economic markets by creating a demand for products that have low greenhouse gas emissions throughout their life cycle.
- ***Product life cycles*** intersect with climate change in a variety of ways, including greenhouse gas emissions through production and transportation, emissions resulting from the use and disposal of the product, and opportunities to sequester and store carbon.

ACTIVITY

9 The Real Cost

Through a simulated shopping activity, students learn about life cycle assessments and the potential impact of their consumer choices on the environment. They explore questions such as: What factors do we use to make decisions about the products we buy? What are the hidden environmental costs of everyday items? Who should pay for these hidden costs?

LCA

Subjects
Biology, Language Arts, Environmental Science, Social Studies

Skills
Analyzing, Comparing and Contrasting, Concluding, Determining Cause and Effect

Materials
Student pages and presentation (see Activity Webpage link below)

Time Considerations
Two 50-minute class periods

Related Activities
This activity introduces life cycle assessment and externalities. It can be followed with Activities 10 and 11, which apply these ideas.

Research Connection
Economists use life cycle assessments to evaluate environmental impacts of products. In the assessment of environmental externalities, researchers are exploring and comparing potential alternatives to traditional extraction and manufacturing in order to reduce or internalize externalities.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section4/activity9

Objectives

By the end of this activity, students will be able to

- list three examples of externalities that can result from product production, consumption, or disposal,
- assess product information to make informed consumer decisions about environmental externalities, and
- compare potential impacts of internalizing the environmental externalities of a consumer product.

Assessment

- Use essay responses from the student page to assess students' understanding of externalities and their knowledge of how externalities can be reduced or internalized.

Background

Every product we buy has environmental impacts, which occur at different stages of a ***product's life cycle***—the period of time that extends from raw material extraction through disposal. These environmental impacts may take the form of air pollution, water use, ***deforestation***, or chemical leaching, for example. By conducting a ***life cycle assessment*** of a specific product, environmental impacts associated with each stage of the product's life cycle can be quantified and measured. Many of those impacts are externalities. An ***externality*** is an impact that affects a third party who is not directly involved in the decision made by a producer or consumer. This "third party" could be another person or it could be the environment.

Here is an example of an externality: What happens when you buy a tank of gasoline and drive around a city? The collective ***emissions*** from automobiles have been shown to lower air quality in cities, which can cause respiratory illnesses. The emissions also contribute ***greenhouse gases*** to the atmosphere.

Additional background information can be found in the **Section 4 Overview**.

However, neither the buyer nor the seller of the gas pays for the full health costs associated with automobile emissions. The negative health impacts on those not directly involved in the transaction are considered *external* to the market, since they are not included in the selling price of the gas. This is called a ***negative externality*** since an added or hidden cost is not reflected in the price.

Externalities can be positive as well. A ***positive externality*** means that effect is beneficial to the third party. For example, a landowner may decide to conserve forested land instead of developing it. While the landowner may receive some benefits from this action, other benefits are *external,* as the action will have positive environmental and social impacts. For example, if you lived next to this landowner, the value of your property may increase simply because many people prefer to live by a forest rather than another house or a business.

KEN KELLY, NATIONAL RENEWABLE ENERGY LABORATORY

Vehicle emissions can lower air quality, cause increased respiratory problems, and contribute greenhouse gases to the atmosphere. These are negative externalities associated with driving gasoline-fueled vehicles.

Cleaner air, cleaner water, and less noise and congestion may be additional positive impacts that you and others reap from your neighbor's choice. This is called a positive externality since an added or hidden benefit is not reflected in the price.

An externality can be addressed, or ***internalized***, by adjusting the price of the good or service to account for the benefits or costs to the third party. There are several techniques for internalizing externalities, but whatever the technique, the goal is to decrease the negative impacts (negative externalities) or increase the positive impacts (positive externalities). This can be done by linking the costs or benefits of those impacts to those who are involved in the economic transaction. For example, externalities can be internalized by the following:

- Producer responsibility: The producer of a product or service could change a behavior or adopt new technologies or practices to minimize negative impacts on the environment or other people.
- Government regulation: The government could pass regulations that force the producer to change their behaviors or to adopt new technologies or practices to minimize negative impacts.
- Consumer responsibility: Some consumers could voluntarily pay an additional fee to pay for products or services with fewer negative externalities.
- Tax: The government could levy a tax to pay for damages and hazards related to the negative externality.

In the gasoline example, the negative externality could be internalized by using taxes on gasoline or charging a toll for people driving within city limits. These measures would make driving into the city more expensive, which would encourage people to decrease that behavior by carpooling or riding a bus. The costs could also be internalized by enforcing stricter regulations on fuel efficiency or emissions. These measures may make it more expensive to buy or maintain a car. In an economic context, this means that

LARRY KORHNAK, UNIVERSITY OF FLORIDA

If a landowner conserves forested land instead of developing it, positive externalities may include improvements in water and air quality.

Systems Thinking Connection

UNDERSTANDING THE BEHAVIOR of a ***system*** in a practical way requires that we focus our area of study by drawing a boundary around that system. Decisions regarding management of the system will depend on where that boundary lies. For example, if we consider the health of an individual by drawing our boundary tightly around that individual, then our health tips will focus on practices or solutions within that boundary (e.g., medications, medical procedures). However, if we draw our boundary around the city where the person lives, then we might focus on other variables that can affect health (e.g., air quality, water quality, or social influences on diet and exercise). The idea isn't that one level of scale is right and another is wrong. Being able to change the boundary of analysis helps us to consider aspects affecting our system that may otherwise get overlooked.

In the context of ***systems thinking,*** an externality is "external" because it creates an impact beyond the normally considered boundaries of the system. Conventionally, economists consider the marketplace to be the extent of their system. Analysis at this boundary has provided important insights about how prices are set. However, this rather narrow approach fails to acknowledge that everything happening in the economic system takes place within a larger environmental system.

In the example given in the background section, the emissions from burning gasoline are not taken into account in the transaction between the seller of the gasoline and the buyer of the gasoline because the price does not reflect the negative impact of those emissions. In this activity, students learn that the impacts of a market exchange that occur outside the market are often overlooked. Instructors can emphasize to students that when a process is studied, the system boundaries one chooses can affect the conclusions one reaches.

In the context of greenhouse gas emissions, we have historically drawn our boundaries narrowly. Our concerns about cars tend to revolve around speed, safety, traffic, or the price of gas. These things have clear and immediate costs—in time and money. As systems thinkers, we should consider drawing our boundaries more broadly to include impacts on air quality and climate with the understanding that these impacts also have costs associated with them.

the drivers are being forced to shoulder the cost of decreasing the emissions caused by their automobile use. Or, a portion of the cost of health care could be charged to the oil companies, which they likely would pass on to consumers in an increased price of gasoline. The term "externality" may be a new term for your students. Be sure to take time to make sure your students understand its use before starting the activity.

Teaching This Content

In this activity, teachers engage students in a scenario of how shoppers might make decisions about the products they buy based on knowledge of the product's externalities. The products are those that students might commonly purchase. This activity is meant to prompt students to think about their individual actions and how those actions influence environmental conditions.

Through this activity, students can increase their awareness of their consumer choices. Students may hesitate to express some factors that influence their shopping choices, especially those factors related to cost. You may wish to remind the class that many Americans have budgetary limitations on what they can afford to purchase. The goal of the activity is not to make students feel bad that they cannot afford an organic cotton shirt or guilty that they have a plastic water bottle on their desk. Rather, the important message is that if we want to encourage ***sustainability*** in a way that everyone can afford, the economic system might need to change. There are both economic and social considerations for all products that are not discussed on the externality cards, which focus only on environmental impacts. These considerations can be part of the overall discussion as students focus on the roles that price, convenience, and habits play

TEACHERS SAY ...

My students loved this particular activity! It was challenging, but fun for them, and they were very engaged throughout! The directions for teachers were very straightforward, and the content fit in nicely with curriculum we have discussed earlier in class.

— Land Resources Teacher, Florida

in our consumer decisions. The specific products available to your students may be different from those portrayed on the card. You may want to adjust the cards to match what is available in your area's stores and markets, as retailers often carry products based on local consumer preference and demand.

Getting Ready

The Activity 9 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section4/activity9).

Download the slide presentation LCA and Externalities from the Activity 9 webpage and review it to determine how much you wish to present to students.

Make copies of the Product Cards and the Externality Cards, enough for your students so there will not be a delay waiting to read a card at each station.

Each student will need one copy of the Money student page, with pieces cut. Alternatively, you could use nickels and pennies, two different color poker chips, Monopoly™ money, or other items you have on hand to represent money.

Doing the Activity

1. Introduce this activity by asking students to name the factors they typically consider when they buy something. Explain that this activity will involve reflecting on those factors and considering whether they are sufficient.

2. Place the Product Cards around the room, with similar products next to each other. Give each student $30 in play money and explain that they can use it to buy a shirt, a snack, and a drink. They do not have to spend all their money. Point out where you have placed the Product Cards and note that there are two similar choices for each product. Ask students to use paper to record their decisions.

3. Instruct students to walk around the room and buy whichever version of the three products they want. To buy a product, students should write down which product they want to buy and its price. Ask them to tally totals for the three products and bring you the correct amount of money. They can do this fairly quickly, relying on their intuition and initial preference for one product over another.

4. Poll students about which products they bought. Keep a tally on the board of the products purchased (see diagram after step 7). Ask students what factors they considered in their buying decisions. Make a class list of the factors.

5. Explain that in addition to factors such as cost, color, and taste, products can be selected based on the environmental impacts that result from the product's creation, use, and disposal. Use the LCA and Externalities slide presentation to introduce students to the concepts of life cycle assessments and externalities.

The **LCA and Externalities** presentation on the Activity 9 webpage will help you introduce students to life cycle assessment, and it also provides examples of positive and negative externalities.

6. Next, place copies of the Externality Cards around the room, and restore $30 to each student. Instruct students to select and purchase products again, but this time students should consider the externality information before deciding which product to purchase. Have students write down their choices, tally their total, and give you the appropriate amount of money.

7. Poll the class to see which product they bought this time and compare it to the tally from the previous round. See the following chart for an example. Ask students if they see

ANNIE OXARART, UNIVERSITY OF FLORIDA

For the second round of shopping, students make their choices after reading information about product externalities.

any obvious trends in the products selected between both rounds. What factors did they consider this time when making choices? Add any new factors to the class list. If students changed their choices, they are opting to send a message by their consumption. If they did not change their choices, the variables they used to make their initial decision have greater importance than the environmental externalities. That is their choice. The real issue is how should we reduce the effects of the negative environmental externalities (see step 9).

Round	**1**	**2**
Cotton Shirt		
Organic Cotton Shirt		
Factors Considered about Shirts		
Farmers' Market Apples		
Grocery Store Apples		
Factors Considered about Apples		
Bottled Water		
Reusable Water Bottle		
Factors Considered about Water Bottles		

8. Split the class into three groups and assign each group one product (apples, shirts, or water bottles). Give each group member a copy of the Product Assessment student page and instruct students to work together to answer the questions. Each group should select one member to report answers to the whole class.

9. Have each group report responses to the following questions:

- What are the environmental externalities of your group's product? Which ones are positive and which ones are negative?
- At what stages of the product's life cycle do the externalities occur?
- How can the negative externalities be reduced?
- Who do you think should pay to reduce the externalities?
- Did group members' opinions vary based on which product they preferred?

10. After each group reports its answers, discuss the following questions as a class:

- Are there any similarities in the externalities of the different products? *Many of the externalities are related to greenhouse gas emissions or water; they occur in similar stages of the product's life cycle.*

TEACHERS SAY …

Two new concepts: externalities and internalizing costs. I am glad for all of the additional information to help the students understand these new ideas. The slide presentation on LCA and Externalities was excellent, clear and concise.

—Honors and AP Biology Teacher, Florida

- Who is currently paying the environmental costs of these externalities?
Some are being ignored, which means future generations will pay if the environment cannot absorb the impact. Some, such as the cost of more frequent severe weather events, are covered by insurance, which may be paid by many people when companies raise insurance rates. Similarly, if droughts affect agricultural production and food prices increase, many people will have to pay more when they purchase food.
- How could these hidden environmental costs become more visible so that consumers can make informed decisions about purchases?
Eco-labels, public service announcements, and teaching people to do their own research are a few possible responses.
- What generalizations can you make that may help you choose products with fewer negative externalities?
Buy locally produced food, organic products, reusable products, for example.
- Systems Reflection: Give an example of externalities (positive and negative) related to urban or rural forests at a local scale, a regional scale, and a global scale.
***Local:** Neighbors of a forest owner might enjoy the increased wildlife or the improved landscape they experience by living next to a forest. A nearby homeowner might not appreciate a tree falling on her house.*
***Regional:** Forests help to protect and sustain a healthy watershed that people within the region rely on for their water supply. Forests also attract and support deer herds that can cause automobile accidents.*
***Global:** Converting forests to pastures and developments may benefit local landowners, but removes the potential for carbon sequestration for the planet.*
- Systems Reflection: Provide one example of an externality not discussed here and describe how changing the boundary of the system can affect our decisions.
Answers will vary. One example is the action of cutting in line. When the system under consideration is simply you and your friend who wants to cut in line, allowing your friend to cut may seem like a good idea. However, when the boundary is drawn around the entire line, including angry people behind you, allowing your friend to cut may not seem so wise.
- For homework, distribute the Externalities Essay student page and ask students to write an essay to describe negative externalities and how they can be reduced or internalized. Students should pick at least one externality for each pair of products and explain how that externality could be internalized.

Modifications

Instead of dividing the class into groups, you can review the products together or even just examine one set of products.

Examine the Product Cards for challenging vocabulary and edit them as necessary. You can also create a vocabulary sheet to go along with any new terminology.

You can conduct the shopping activity over three days and have the students take home the Externality Cards to read as homework. Bring in product samples for students to see and examine.

Enrichment

Challenge students to select a product and to think outside the box about how to make that product more environmentally friendly. To inspire students, show examples of products, buildings, or other items that are created with zero waste, biomimicry design, or sustainable practices. The Whole Systems and Life Cycle Thinking website listed in the Additional Resources section provides information and examples that may be helpful to get students started.

Additional Resources

The Secret Life of Things
www.thesecretlifeofthings.com
This website provides a set of short animated videos exploring the hidden environmental impacts of everyday things. Each video has a free pack of learning resources.

The Story of Stuff Project
www.storyofstuff.org
This website contains links to several short videos related to how things are created, used, and thrown away. Video scripts and resources are available for using these materials in classrooms.

Stuff: The Secret Lives of Everyday Things
John Ryan and Alan Durning, Sightline Institute, 1997
http://www.sightline.org/research/stuff/
This book explores how nine common items are made. Each product is something that you might use or buy, such as coffee, a newspaper, or a t-shirt. The website provides a curriculum guide to accompany the book and a short quiz about the book's content.

Whole Systems and Life Cycle Thinking
Autodesk® Sustainability Workshop
http://sustainabilityworkshop.autodesk.com/products/whole-systems-and-lifecycle-thinking
This website contains a short video connecting life cycle assessment to systems thinking. Scroll down to the bottom of the page to download the materials for a class activity on how systems thinking can inform one's assessment of common household appliances.

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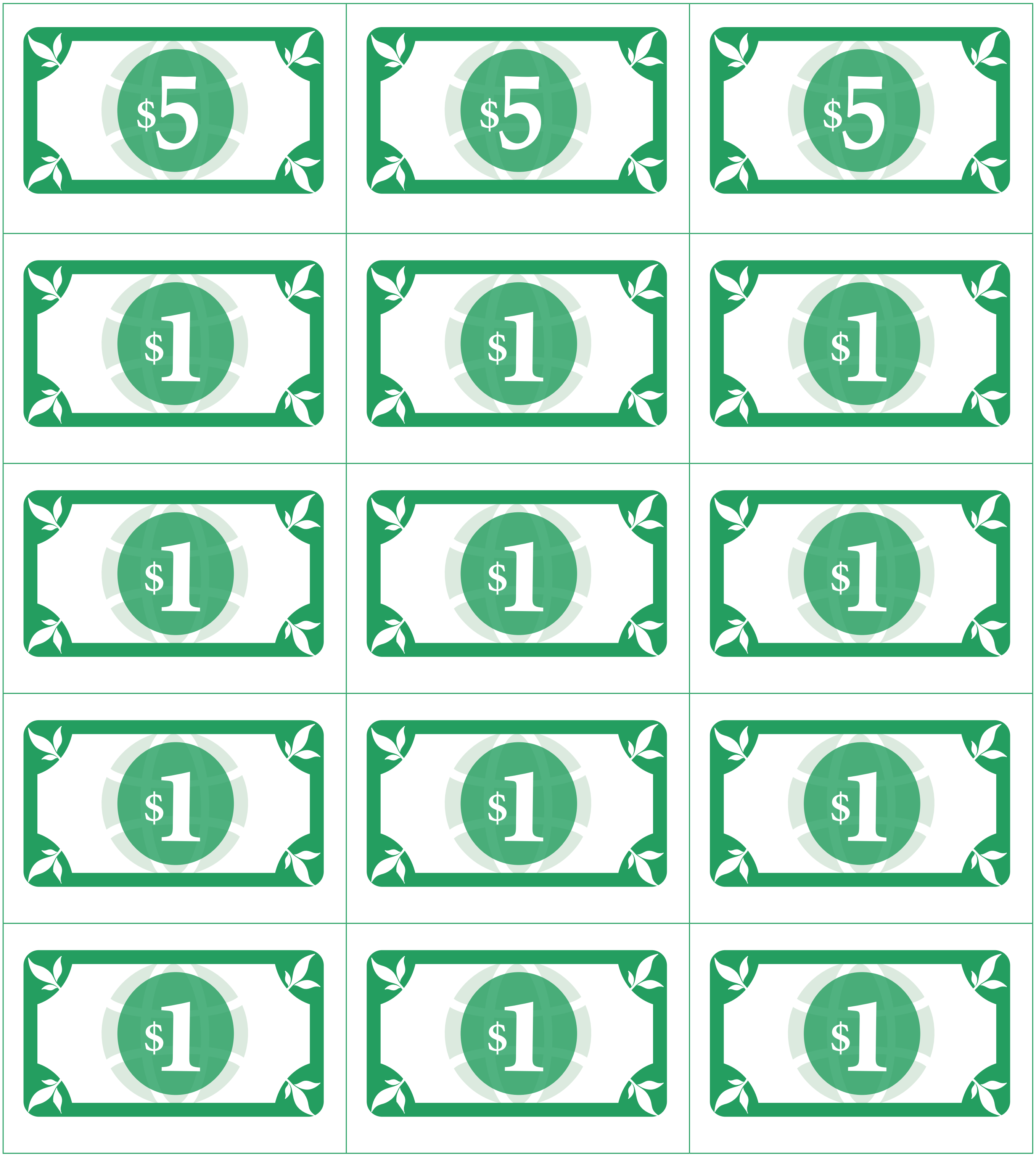
TEACHERS SAY ...

I thought the essay was a great way to assess learning and my students showed a high level of mastery on their essays after the activity.

— Earth/Space Science Teacher, Florida

Money



Product Cards

Cotton Shirt
$5.00

Organic Cotton Shirt
$16.00

Bottled Water
$2.00

Reusable Water Bottle
$10.00

Farmers' Market Apples
$2.00/lb

Grocery Store Apples
$1.00/lb

Externality Cards (1 of 2)

Cotton Shirt

Cotton production can involve the use of pesticides. From planting to harvest, cotton is often treated with herbicides, fungicides, and insecticides. Pesticides can be damaging to organisms that live in the soil and can be washed into streams when it rains, polluting waterways.

Cotton fields are also often irrigated. On average, it takes approximately 659 gallons of water to produce the cotton used to make a shirt (Water Footprint Network).

Researchers have calculated that an average cotton shirt has a carbon footprint of 6.34 kg of carbon dioxide (Continental Clothing Co. Ltd, 2009).

Organic Cotton Shirt

Organic cotton is grown without using synthetic chemicals. This means that only natural fertilizers, pesticides, and weeding techniques are used to produce the cotton. As a result, fewer pollutants may enter waterways. Organic cotton is often grown as a rotation crop, which prevents the soil from becoming depleted of nutrients and allows the soil to hold more water. This may allow farmers to use less water for irrigation (Jorgensen et al., 2006).

Only natural oils are used during the cleaning and spinning process. These oils easily biodegrade, thereby reducing the number of times the shirt needs to be washed during production. In addition, only natural dyes are used (Jorgensen et al., 2006).

Researchers have calculated that the total carbon footprint of an organic cotton shirt is 2.34 kg of carbon dioxide (Continental Clothing Co. Ltd, 2009).

Bottled Water

Petroleum, which is a nonrenewable resource, is used to make most plastic bottles, and fossil fuels are required to ship those bottles of water around the world. This is an energy-intensive process that produced over 2.5 million tons of carbon dioxide emissions in 2006 (Pacific Institute, 2012). Not only do these greenhouse gas emissions contribute to climate change, but the whole process uses a great deal of water too. Approximately three liters of water are used to manufacture one liter of bottled water (The Water Project).

Most likely this bottle will be used only once and then thrown away. If it is made of PET plastic it can be recycled, otherwise it will take more than 1,000 years to biodegrade in a landfill (The Water Project).

Externality Cards (2 of 2)

Reusable Water Bottle

This reusable bottle is made from aluminum. Aluminum production is one of the most energy-intensive industries contributing to greenhouse gas emissions (Tufvesson, 2011).

Since the bottle can be refilled from any tap, the transportation cost for the water is significantly lower than for bottled water. The bottle can be reused, which reduces waste. When the bottle is disposed of it can be recycled; in fact, 75 percent of the primary aluminum ever produced is still in use today due to active recycling programs (Tufvesson, 2011).

Grocery Store Apples

In the Southeast, many of the apples we buy come from Washington, as this state is responsible for producing more than half of the apples eaten in the United States. Washington apples travel more than 2,000 miles to the southeastern United States and the trains or trucks that transport them typically use fossil fuels, such as diesel. This results in air pollution and carbon dioxide emissions that contribute to climate change (WSU Extension, 2014).

Apples that travel a great distance are packed in heavy boxes to protect the fruit, which creates more waste. In addition, preservatives are often used to maintain freshness for fruit that travels long distances before reaching the consumer (Lanford, 2011). Washington apples are available year-round in southern grocery stores.

Farmers' Market Apples

Apples sold at a farmers' market in the Southeast may come directly from a local farmer or from a collection of farmers in that state or region. Many farmers' markets sell organic produce and these apples may have spots from insect damage.

Farmers' markets are usually not open every day, or even all day. Apples are only available in late summer and fall, depending on the variety and whether the farmer has cold storage. Because the farmers are local, the money they earn from selling food supports the local economy. Since the apples travel a considerably shorter distance than those sold at the grocery store, transportation fuel consumption, air pollution, and greenhouse gas emissions are reduced. Research shows that the carbon dioxide emissions from transporting locally produced apples can be 40 times less than the emissions for transporting conventional ones, depending on how both are transported (Bentley & Barker, 2005). Also fruit that is freshly picked and sold immediately will be closer to peak ripeness, which could mean increased flavor and nutrition (Nutrition.gov, 2014).

Product Assessment (1 of 2)

NAME ______________________ GROUP MEMBERS ______________________

1. Which product did each of you choose during each round? Why?

2. What are the advantages and disadvantages of each product?

Product 1: ______________________

Advantages	*Disadvantages*

Product 2: ______________________

Advantages	*Disadvantages*

Product Assessment (2 of 2)

3. Which of the disadvantages are considered negative externalities? Which of the advantages are considered positive externalities?

4. At what stage in the product's life cycle do the negative externalities occur? (Hint: The life cycle stages are raw material extraction, processing, manufacturing, product use, and disposal.)

5. How can these externalities be reduced or internalized?

6. Who should be responsible for reducing negative externalities? Who should pay the extra cost? (For example, should the company or producer of the product pay? Should the users of the product pay? Should everyone pay through increased state or federal taxes or subsidies?)

7. Do the responses in your group for question 6 vary based on which product individuals in the group preferred?

Externalities Essay

Using the information you learned from the shopping exercise and the group discussion, write an informative essay to answer the following question: What are externalities and how they can be reduced or internalized? For each product (water bottles, apples, and t-shirts), pick at least one externality and explain how that externality could be internalized.

Remember, a good informative essay

- has a clear introduction;
- states a focus/topic clearly, precisely, and thoughtfully;
- uses specific evidence/information to support and develop the topic and explains that evidence;
- concludes effectively;
- uses precise language; and
- shows proper use of standard writing conventions (e.g., punctuation, spelling, capitalization, grammar, and usage).

You may want to take some time to plan your essay before you begin writing. Be sure to proofread your essay when you are finished.

ACTIVITY

10 Adventures in Life Cycle Assessment

By performing a play or through group presentations, students investigate life cycle assessment (LCA) data for three types of outdoor dining furniture (plastic resin, cast aluminum, and pine) and make conclusions about the relative impact of the products on global climate change.

Subjects
Biology, Environmental Science, Language Arts, Mathematics, Social Studies

Skills
Analyzing, Communicating, Concluding, Determining Cause and Effect, Identifying Relationships and Patterns, Organizing Information, Predicting

Materials
Student pages, presentation, and answer key (see Activity Webpage link below); Optional: poster materials, props, and costumes

Time Considerations
Three Act Play: Three to four 50-minute class periods; One Act Play: Two to three 50-minute class periods
Student presentations: Two to three 50-minute class periods

Related Activities
Students should have an understanding of climate change (Activity 2) and externalities (Activity 9). This activity can be followed with exercises that apply this information to students' purchasing decisions (Activity 11) or climate change mitigation (Activity 12).

Research Connection
Economists are conducting life cycle assessment research comparing environmental impacts for different products that provide the same functions. A comprehensive life cycle assessment can help researchers quantify the pros and cons of different products and, in the case of this module, understand the role of forests and wood products in mitigating climate change. Databases containing information that researchers use to create LCAs can be found online (see Enrichment section of this activity).

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section4/activity10

Objectives

By the end of this activity, students will be able to

- describe the stages of a product's life cycle and how greenhouse gas emissions may be generated during those processes, and
- compare life cycle data for two or more products to decide which product would reduce greenhouse gas emissions.

Assessment

- Ask students to draw a life cycle diagram, labeling each stage of the diagram and providing a brief description of each stage.
- Ask students to write a report summarizing the life cycle assessment of the outdoor dining furniture. The report should include an introduction to life cycle assessment, a description of the products analyzed, life cycle data for each product, and a discussion comparing each product's impact on global climate change.
- Ask students to decide which type of dining furniture the school should buy and to defend their choices by describing their personal values and the consequences of their choices using life cycle assessment information.

Background

To evaluate and compare the environmental impacts of products, scientists take a detailed look at the entire life cycle of a good or service—which means they conduct a ***life cycle assessment***. A ***product's life cycle*** begins with extracting and processing raw materials, continues through the manufacturing, includes how the product is used, and ends with disposal of the product (figure 1). At every step, resources and energy are used and ***greenhouse gas emissions*** and other byproducts are created. Life cycle assessments identify these resources and emissions and summarize their environmental effects. This information can be used by scientists, policymakers, manufacturers, and citizens to make decisions about which products to produce and purchase. In many life cycle assessments, transportation of items from stage to stage is another variable (shown as T in figure 1). In the assessments provided here, transportation has been included in each stage.

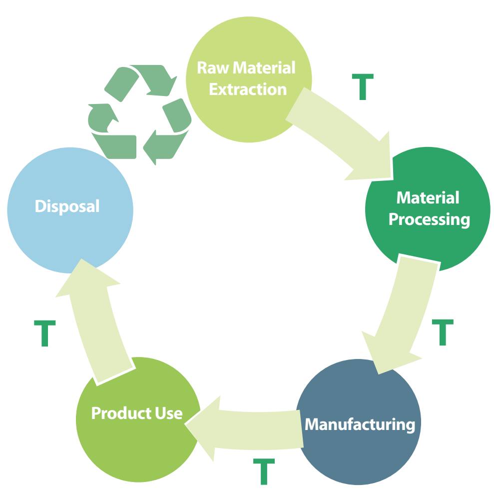


Figure 1. Steps in Life Cycle Assessment.

Additional background information can be found in the **Section 4 Overview** and in **Activity 9**.

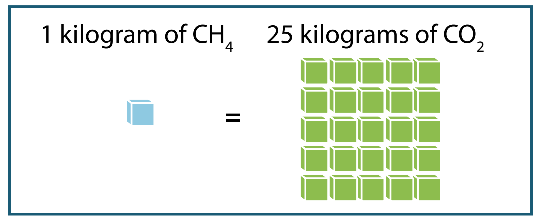
The National Renewable Energy Laboratory (NREL) U.S. Life-Cycle Inventory Database is a good resource to access data for life cycle assessments (http://www.nrel.gov/lci/). Data for utilities, transportation, and basic mining and forestry materials are included in this database. The life cycle data provided in this activity was calculated using the U.S. Life-Cycle Inventory Database, and a step-by-step tutorial for using this professional database to find information for other products is available on the Activity 10 webpage.

The life cycle data provided in this activity compares three types of outdoor dining furniture and focuses on greenhouse gas emissions resulting from the manufacturing, use, and disposal of the product. We focus on greenhouse gas emissions so that students can calculate the ***global warming potential*** of each of the three furniture sets.

Greenhouse gases trap heat in the Earth's ***atmosphere***. A certain amount of greenhouse gases are necessary to keep the Earth warm enough to sustain life. However, increasing amounts of greenhouse gases in the atmosphere create a gradual increase in the average global temperature, which is known as ***global warming.*** More information about global warming can be found in the **Section 1 Overview** and **Activity 2: Clearing the Air**. Greenhouse gases include the following:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)
- Water vapor (H_2O)

Of all the greenhouse gases, atmospheric carbon dioxide levels have increased the most in recent years. However, methane and nitrous oxide are important greenhouse gases to consider in the life cycle assessment as well. Not all greenhouse gases are equal. Some gases are able to capture more energy than others. For example 1 kilogram of methane in the atmosphere will trap about 25 times as much heat energy over a 100-year period as a kilogram of carbon dioxide. Therefore, methane is defined as having a global warming potential of 25. When scientists measure the impacts of greenhouse emissions, they often use the term ***carbon dioxide equivalents***. This is the basic unit for measuring the global warming potential of all emissions. Since 1 kilogram of methane traps as much heat as 25 kilograms of carbon dioxide, that 1 kilogram of methane has a global warming potential of 25 kilograms of carbon dioxide equivalents.



Carbon dioxide equivalents are a measure of global warming potential, expressed in the amount of carbon dioxide that would cause the same amount of warming. As seen here, 1 kilogram of methane (CH_4) is equivalent to 25 kilograms of carbon dioxide (CO_2).

Teaching This Content

This activity introduces the highly technical process of assessing a product's life cycle, and it is likely to involve more detail than students thought possible. After one or two examples, you might see if they can guess the steps in the process for the third. While our intuition about environmental impacts of products might be a reasonable guess, it is handy to have real numbers to lean on, especially for making recommendations that the school could use to reduce emissions! Also, if you have used **Activity 5: Managing Forests for Change**, please note the potential confusion between causal loop diagrams and life cycle diagrams explained in the Systems Thinking Connection box.

Learning about the environmental impacts of all the stuff we buy can be overwhelming

Systems Thinking Connection

IN THIS ACTIVITY, students explore diagrams of several different life cycles. Some students may confuse these diagrams with the ***causal loop diagrams*** from Activity 5. Instructors can explain that these are two different tools designed to emphasize different aspects of a ***system.*** In causal loop diagrams, the arrows represent cause-effect connections between different parts of the system. For example, "Atmospheric Carbon Dioxide → Heat Energy in the Atmosphere" in a causal loop diagram suggests that increasing the amount of carbon dioxide in the atmosphere will cause an increase in the amount of heat energy trapped in the atmosphere.

Conversely, the life cycle diagrams are designed to show material flowing through a system over time. Here, the arrows represent actual material flows over time. For example "Refined Oil → Plastic Pellets" suggests that the atoms in the refined oil are rearranged into molecules of plastic. Those pellets are then combined with other materials and rearranged into plastic furniture. The systems enrichment exercise is designed to give students practice seeing this important distinction.

and even depressing. Remind students that all products have some environmental impact. The focus is on weighing the costs and benefits associated with a product or service. Students may consider choosing to not buy anything because whichever product they select creates such a large impact on the environment. While companies are invested in encouraging us to buy more and replace out-of-fashion items frequently, students should consider the impact of their purchases. Maybe they don't need a new shirt just because it is attractive; maybe repairing a broken chair will extend its life span. Shopping at a thrift store is one way to give old products a new life. Suggest that students consider when it is appropriate to buy new things.

This activity integrates all aspects of STEM (science, technology, engineering, and math)! Students gain an understanding of the research behind the methods and technology that goes into how things are made, and they discover the intricate processes involved with manufacturing products. The life cycle analysis is typically done through engineering, the discipline that gives us technology and the ability to produce the outdoor furniture featured in this activity. In addition, students need to use mathematics to analyze the data to determine the "best" product. This activity provides a good opportunity to let students know that engineering and math are not always as complicated as building a rocket. Examples of STEM are all around us.

Getting Ready

The Activity 10 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section4/activity10).

If your students are not familiar with life cycle assessments, you may want to provide an overview of this topic using the LCA and Externalities presentation on the Activity 9 webpage.

Based on available time, number of students, student ability, and student interest**, you may choose to conduct this activity by performing a play or through student presentations**. The information for conducting life cycle assessments on three types of outdoor dining furniture is provided in both formats.

You may also mix and match the two delivery mechanisms by performing one or two of the acts, and providing the Life Cycle Information student pages for the remaining product(s).

Perform a Play

Students act out the play in class, and as the characters discover life cycle data for each product, the audience records this information using the Comparing Outdoor Furniture student page. The play is divided into three acts—one for each set of furniture. Each act has

TEACHERS SAY ...

My students are used to project-based instruction, so they tried out for parts after an oral reading during class time and the class voted on who would play each part. The class shared their play with the other section of the 8th grade class.

—Middle School Science Teacher, Arkansas

ANNIE OXARART, UNIVERSITY OF FLORIDA

Depending on time availability and student interest, you can choose whether to conduct this activity by performing a play or through student presentations.

ten or eleven actors and takes 30 to 35 minutes to perform. The acts can be performed on separate days or together if you have a long class period. There is also a one act version of the play with 11 scripted parts that includes a brief description of the life cycle of all three types of furniture and takes one or two class periods to complete. After the performance, students discuss and compare each product's impact on global ***climate change***.

- Download the LCA Play Script from the Activity 10 webpage and copy the number needed depending on the number of actors and acts performed.
- Download the LCA Play slide presentation from the Activity 10 webpage. This includes images for the stage backdrop and the notes on emissions.
- Make copies of the Comparing Outdoor Furniture student page for each student.
- You may wish to invite other students, teachers, or parents to enjoy the play. Try to make time for students to practice before inviting others to the performance. Encourage students to bring props!
- Note that each act of the play involves three review questions for the audience to answer during the play. Some of these come directly from the content of the play. Others concern key climate change concepts that are covered in Activity 2 of this module. If you elect to perform the play without working through other parts of the module, we recommend that you go through the background section for Activity 2. Alternatively, you can use these questions as a WebQuest or simply replace them with something that will review key concepts you have been covering in class.

Student Presentations

Using the Life Cycle Information student pages, student teams give a short presentation to explain their product's life cycle and report on the greenhouse gas emissions resulting from each stage. As each team presents, students in the audience complete the Comparing Outdoor Furniture student page. As a class, students discuss and compare each product's impact on global climate change.

- Divide the class into three teams: Plastic Resin, Cast Aluminum, and Pine. Make copies of the appropriate Life Cycle Information student pages, one for each student in each group. If there are enough students in each team, they could subdivide to each present a different stage of the life cycle.
- Make copies of the Comparing Outdoor Furniture student page, one for each student in class.

Doing the Activity

1. To introduce the topic of the life cycle assessment, ask students to select one item they have recently purchased. On a piece of paper, ask students to brainstorm ideas about the materials and processes it took to make that product; what resources are used to care for or maintain the product; and what happens to it when it is no longer useful. Ask a few students to share their ideas.

2. Explain that life cycle assessments are used to measure and calculate the environmental impact of a product. Draw the life cycle diagram on the board (see figure in Background section), and ask students if they can see where their ideas fit into the diagram and whether there are any circles that would require more information to complete.

3. Tell students to imagine that they have been charged with choosing new outdoor dining furniture for the school's cafeteria patio. Because your school is concerned with its environmental footprint, the students have to investigate the life cycles of three types of outdoor dining furniture before making a decision: a table and four chairs made from plastic, from aluminum, and from wood. Tell them that for these assessments, they will focus on greenhouse gas emissions. Remind students that carbon dioxide, methane, and nitrous oxide are the major greenhouse gases. Through either the play or presentations, students gather real data for greenhouse gas emissions for each step of each product's life cycle.

4. Ask students to predict which product they think will have the lowest greenhouse gas emissions. Which do they think will have the highest? Why?

5a. Stage the Play

- Based on the number of acts you plan to perform, and the number of students in your class, assign characters, or allow students to choose their own characters, and pass out copies of the script. Since most of the characters are on the stage for only a portion of the play, some students will be able to share scripts.
- For homework, ask students to read through the script and become familiar with their roles. They may wish to bring props or "dress" for the part on the day of the performance. You can encourage your students to personalize the script by making minor edits without removing any information. They may want to change some of the jokes or characters to make the play their own.
- The LCA Play slide presentation provides an instant "background set" for the play. Slides also provide the life cycle data for each stage, which students in the audience need to write down on the Comparing Outdoor Furniture student page. As the play progresses, allow some time for the student audience to record the data on student pages. You can advance the slides as noted in the script or assign a student to do this.

5b. Student Presentations

- Divide the class into three groups (plastic resin, cast aluminum, and pine). Pass out the appropriate Life Cycle Information student pages to each group member.
- Provide time for the students to read their Life Cycle Information student pages and to organize their presentations. Suggest that one or two people in each group cover each life cycle stage, so that all group members can participate in the presentation. During the presentation, students should describe what happens during that stage and provide life cycle data.
- Encourage students to make presentations interesting. If they give a slide presentation, they can include relevant photos or graphics. They can also use the board, flip chart paper, or any other visual presentation style. They should finish tasks not completed in class as homework and come to the next class prepared to give their presentations.
- While each group presents, the audience should record data on the Comparing Outdoor Furniture student page.

6. After the performance or presentations, give students a few minutes to complete the calculations for the greenhouse gas equivalents on the Comparing Outdoor Furniture student page. An answer key is available on the Activity 10 webpage. Then use the following wrap-up questions to guide a class discussion:

- What are carbon dioxide equivalents? How did this change the life cycle data? *Some gases have a larger effect per mass than others. For example, methane is more than twenty times stronger than carbon dioxide per unit. In order to combine the warming effects of different gases, scientists express the warming impact of methane and nitrous oxide emissions in the common unit of carbon dioxide equivalents.*

TEACHERS SAY ...

Students enjoyed the activity because it got them out of their seats. And they learned that they need to educate themselves about consumer choices and product selection.

— AP Environmental Science Teacher, Florida

TEACHERS SAY ...

All materials were at a perfect level for my students. I will do the activity again and will choose the presentation option again.

—*AP Environmental Science Teacher, Kentucky*

- What surprised you as you learned about the life cycles of outdoor dining furniture?
  Answers will vary. Encourage students to compare different steps in the life cycles.

- What conclusions can you make about the relative impact of each product on global climate change?
  The aluminum set has a much larger impact than the other two. The wood set has the lowest impact of the three.

- How could production change to reduce emissions?
  Answers will vary. Have students identify the steps with the highest emissions. For example, the disposal stage represents most of the emissions associated with the wood set. Finding nontoxic ways to treat the wood would mean that it could be composted instead of taken to the landfill, significantly decreasing its climate change impact. Some wood is naturally more insect and fungus resistant than pine, which is why redwood and teak are often used for outdoor furniture. But that would involve additional product life cycle considerations!

- What factors do people usually consider when choosing between similar products?
  Price and quality of the products are typically considered. This activity is designed to encourage students to think beyond these basic factors.

- Should life cycle information be available for more products? Why or why not?
  Answers will vary. It is certainly useful information, but can be time consuming to obtain.

- Based on what you learned from the furniture comparisons, what types of general questions can you ask about a product prior to buying it? Using it? Disposing of it? Think of items that you tend to buy: what should you know about them to decide which is better for the environment?
  Answers will vary. Encourage students to consider if a process involves high temperatures and large chemical inputs (such as aluminum). Does using the product result in significant greenhouse gas emissions? How long can you use the product before disposing of it? Can the product be reused or recycled?

- Draw a basic life cycle diagram for a tree or an animal (e.g., seed to sprout to sapling to adult tree to dead tree). Ask students where the "raw materials" come from during the various "production" steps. Ask them where the materials go during the "disposal" step.
  Point out that all life cycles in nature are circular. Materials are reused over and over again. Many leaders in sustainable business suggest that this should be the model for industry as well. The aluminum furniture set is an example of a circular cycle that uses recycled materials even though some primary aluminum is still used in the process.

- Systems Reflection: In what way is LCA a tool for improving systems thinking?
  One of the key insights that systems thinking can provide is a greater awareness of how we are connected to the world around us. LCA is a tool for doing just that. It increases the knowledge that consumers have about the social and environmental systems that are necessary to provide the products and services that we consume.

7. Summarize this activity by reviewing the steps of a life cycle assessment and the importance of quantifying impacts with a life cycle assessment when making recommendations for purchasing. You might suggest that students use this information when making their own purchasing decisions in the future. This process will be helpful for **Activity 11: Life Cycle Assessment Debate**, which is a good follow-up activity.

Types of Furniture

To shorten this activity, students can investigate one type of furniture to learn the life cycle steps and then discuss how these steps may differ for the other two types of furniture.

Modifications

If you are conducting either the three- or one-act play, you may want to ask for assistance from the drama club at your school or from parent volunteers. If you teach multiple classes of the same subject, you can divide the play or presentations into sections by class and come together for a group presentation.

Some of the content on product information sheets might include vocabulary that is new to your students. Edit the text to their reading level or have students look up new vocabulary words for homework or a separate assignment.

If limited by time, you can just investigate one type of furniture so students can learn the steps of the life cycle and then have a group discussion about how about these steps may differ by product type.

Enrichment

Use the Create Your Own LCA tutorial on the Activity 10 webpage to have students investigate and calculate greenhouse gas emission data for another product. Concrete is another material commonly used for sturdy outdoor picnic tables. Challenge students to conduct an LCA for this product and compare!

Systems Enrichment Exercises

YOU CAN HELP YOUR STUDENTS BETTER UNDERSTAND THE DIFFERENT WAYS WE CAN LOOK AT SYSTEMS by reinforcing that a causal loop diagram shows us the cause-effect connections between different parts of a system, and a life cycle diagram shows us one path that a set of matter (or atoms) follows through a system. The exercise, **The Impacts of Demand for Sustainable Wood**, was developed to help students see the difference between life cycle diagrams and causal loop diagrams—two different tools with two different functions. Additionally, this exercise uses a causal loop diagram to help students understand how demand for sustainable wood plays an important role in protecting forests. This exercise can be found on the Activity 10 webpage.

TEACHERS SAY …

When using this activity, I incorporated the "Story of Stuff" from the resource section of The Real Cost to help introduce the concept of life cycle assessments.

—AP Environmental Science Teacher, Florida

Have students consider the durability of the materials and the frequency with which tables or chairs might need to be replaced. For example, the plastic chairs might easily break, or students might carve into the wood. While aluminum or concrete have more greenhouse gas emissions, they might be more durable in the long run.

Additional Resources

Consortium for Research on Renewable Industrial Materials (CORRIM)
www.corrim.org
This website provides many resources related to life cycle assessments, including several videos, presentations, and fact sheets.

Life Cycle Impacts of Forest Management and Wood Utilization on Carbon Mitigation: Knowns and Unknowns
Bruce Lippke et al., 2011
http ://www.corrim.org/pubs/articles/2011/FSG_Review_Carbon_Synthesis.pdf
This short article, published in *Carbon Management*, examines the complexities in accounting for carbon emissions in life cycle analyses and offers information on the many different ways that wood can be used.

The Life Cycle of Everyday Stuff
Mike Reeske and Shirley Watt Ireton, National Science Teachers Association, 2001
http://www.nsta.org/store/product_detail.aspx?id=10.2505/9780873551878
This supplemental curriculum guide uses central science concepts to explore the energy, raw materials, and waste issues that are associated with manufactured products.

U.S. Life Cycle Inventory Database
National Renewable Energy Laboratory
www.nrel.gov/lci
This database helps life cycle assessment practitioners answer questions about environmental impact. It provides accounting of the energy and material flows into and out of the environment that are associated with producing a material or component, or assembling products in the United States.

Which Do You A-Door? Comparing the Energy Needed to Make Wood and Steel Doors
Melissa Huff, Robert Ross, and Janet Stockhausen; U.S. Forest Service, 2009
www.naturalinquirer.org/Comparing-the-Energy-Needed-to-Make-Wood-and-Steel-Doors-a-82.html
This *Natural Inquirer* article, written for middle school students, describes research that compares portions of the life cycle for wood and steel doors.

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Life Cycle Information:

Plastic Resin Furniture (1 of 3)

The plastic resin set of furniture is made from polypropylene (pol-ee-proh-puh-leen) resin—a plastic polymer with a wide range of uses, including car parts, diapers, and, of course, outdoor furniture. It is made from by-products of processing natural gas and refining crude oil. Since each piece of the set is made from one mold, no fasteners are required. The total mass of the four chairs and table is approximately 30 kilograms (kg). All emissions reported here are based on this mass.

MUMUDESIGN.COM

A set of plastic furniture, such as the one shown here, is made from polypropylene resin.

Oil and Natural Gas Extraction

More than 300 million years ago, countless zooplankton, algae, and diatoms died and sank to the bottom of oceans all over the globe. After eons of pressure and geological processes, the planet has been left with billions of gallons of oil, also called "petroleum." Crude oil is generally located in cavities about a mile deep underground. Sometimes the oil is under pressure that is high enough that drilling a deep hole causes it to gush out of the earth—an event that has caused some oil prospectors to dance excitedly as their new oil wells shower them in a brown, gooey mess. Most of the time, however, it must be pumped to the surface. Oil from the ground usually contains water. This water is removed before sending the oil to a refinery. The natural gas is captured, but some leakage of gas always occurs when bringing petroleum to the surface. In addition, it takes energy to collect these substances and prepare them for refining and processing. The emissions that result from this step of the life cycle are reported in the following table.

Stage of Life Cycle	*Oil and Natural Gas Extraction*
CO_2 Emissions (kg/set)	4.20
CH_4 Emissions (kg/set)	0.164
N_2O Emissions (kg/set)	0.00000588

Refining Crude Oil and Processing Natural Gas

Most of the refineries in the United States are in Gulf Coast states. The majority of our oil (62 percent) is imported; 32 percent comes from the lower 48 states, and the remaining 6 percent comes from Alaska. The top three providers of foreign oil to the U.S. are Canada, Saudi Arabia, and Mexico. Scientists and economists use a weighted average of the emissions associated with transporting oil to U.S. refineries by pipeline or ship from these sources.

Once at a refinery, impurities are removed from the oil through a series of chemical processes. During this process, hydrocarbons such as methane and propane are removed from the oil. These hydrocarbons are used in many different products, including the production of polypropylene. The greenhouse gas emissions associated with the transportation of oil to U.S. refineries and

Life Cycle Information: Plastic Resin Furniture (2 of 3)

refining the oil and natural gas are reported in the following table.

Stage of Life Cycle	*Refining Oil/Processing Natural Gas*
CO_2 Emissions (kg/set)	6.87
CH_4 Emissions (kg/set)	0.0571
N_2O Emissions (kg/set)	0.0000350

Producing Polypropylene Resin

Propylene is made from a combination of chemicals derived from oil and natural gas, including hydrocarbons such as ethane and propane. These molecules are put through a process called "thermal cracking." The term "cracking" refers to a process in which heavy molecules are broken down into smaller ones. In this case, the hydrocarbons are combined with steam and the mixture is heated to around 1000 degrees Celsius (° C) or 1832 degrees Fahrenheit (° F). The combination of high temperature and pressure breaks the larger hydrocarbons into smaller molecules, including propylene. The propylene must then be separated from the other products that result or are leftover from this process.

The next step is to convert the propylene into polypropylene. The prefix "poly" means many. Polypropylene is a molecule made up of many propylene molecules connected together. The polymerization of propylene is accomplished through the use of catalysts at fairly moderate temperatures (80 to 90° C or 176 to 194° F) and high pressures (30 to 35 atmospheres). The greenhouse gas emissions listed in the following table represent emissions associated with the propylene portion of the thermal cracking stage as well as the polymerization of propylene into polypropylene.

Stage of Life Cycle	*Manufacturing Polypropylene*
CO_2 Emissions (kg/set)	32.4
CH_4 Emissions (kg/set)	0.427
N_2O Emissions (kg/set)	0.000280

Manufacturing the Furniture

Polypropylene in the form of small pellets (tiny beads) is shipped by rail to furniture manufacturing plants. Those pellets are melted and mixed with other substances that make each type of plastic a little different. The mixture is injected into a mold using a 1000-ton injection molding machine. After the resin hardens, the mold is opened, small amounts of resin are trimmed from the edges, and the piece is boxed for shipment. The greenhouse gas emissions reported

FRC INDUSTRIES, INC.

Small polypropylene pellets are packaged and shipped to manufacturing facilities that create plastic products.

Life Cycle Information: Plastic Resin Furniture (3 of 3)

here represent direct energy use necessary for melting, mixing, and injecting the polypropylene resin in to the molds.

Stage of Life Cycle	*Manufacturing Plastic Furniture*
CO_2 Emissions (kg/set)	15.6
CH_4 Emissions (kg/set)	0.0372
N_2O Emissions (kg/set)	0.0000622

Use/Maintenance

Maintenance and upkeep of the plastic resin patio furniture is minimal, consisting of washing with soap and water. Therefore, greenhouse gas emissions associated with this stage of the life cycle are assumed to be insignificant and not included in this assessment.

Stage of Life Cycle	*Use*
CO_2 Emissions (kg/set)	0.00
CH_4 Emissions (kg/set)	0.00
N_2O Emissions (kg/set)	0.00

Disposal

While many plastic resins can be recycled in curbside recycling programs, the mixture resulting from the manufacturing process of this patio furniture is not easily recyclable. Therefore, disposal consists of a trip to a community landfill. One of the criticisms of plastic resin is that it takes a very long time to decompose. Plastic can exist in a landfill for hundreds of years. In the context of greenhouse gases, this trait works in favor of plastics. Over a one hundred-year period, only 6 percent of the carbon in the plastic set will have decomposed and formed greenhouse gases— 4 percent is carbon dioxide and 2 percent is methane. The greenhouse gas emissions reported here include these emissions as well as those associated with the collection and management of solid waste.

ROBERT GORDON, DEKALB COUNTY

Most plastic chairs are taken to a landfill after being thrown away.

Stage of Life Cycle	*Disposal*
CO_2 Emissions (kg/set)	12.8
CH_4 Emissions (kg/set)	0.292
N_2O Emissions (kg/set)	0.0000319

Life Cycle Information:

Cast Aluminum Furniture (1 of 3)

ANNIE OXARART, UNIVERSITY OF FLORIDA

An aluminum set of dining furniture is made of cast aluminum.

The aluminum set of dining furniture is made of cast aluminum. While manufacturers often use primary aluminum, we have based these calculations on a combination of primary and recycled aluminum often produced by aluminum plants in the United States. The energy requirements are decreased substantially by the inclusion of recycled aluminum. The mass of aluminum in the four chairs and table is approximately 60 kilograms (kg).

Extracting Aluminum

Aluminum manufacturing involves use of both primary aluminum from bauxite, an aluminum ore, and secondary aluminum, which is recycled from aluminum scrap.

Producing primary aluminum first requires mining bauxite from the ground. While aluminum is the third most plentiful element in the Earth's crust, it's usually found as part of a chemical compound with other elements. Trying to produce pure aluminum from most of these compounds is very expensive. It would cost more to produce the aluminum than the aluminum is worth. Bauxite, a type of rock that contains high amounts of aluminum is the exception, though even with bauxite, producing pure aluminum requires a lot of effort. First, the bauxite must be mined. In some cases, the bauxite is found in relatively soft rock that can be easily dug up, often in open-pit mines. In other cases more substantial drilling and the use of explosives are required. Mixing secondary aluminum with the primary aluminum decreases the amount of bauxite that must be mined. Here we assume that the outdoor furniture is made of 50 percent recycled aluminum since we want to consider furniture that will have the least impact on the climate.

Stage of Life Cycle	*Bauxite Mining (for ½ Primary Material)*
CO_2 Emissions (kg/set)	10.1
CH_4 Emissions (kg/set)	0.00203
N_2O Emissions (kg/set)	0.000221

Processing Aluminum

As previously mentioned, processed aluminum is a mixture of primary and secondary aluminum. Most of those emissions, however, are the result of the energy-intensive process of producing pure aluminum from bauxite. Once out of the ground, the bauxite is crushed into small pieces and sent to a processing plant. At the processing plant, the pieces are brought to a high temperature and pressure and mixed with sodium hydroxide in order to dissolve the ore and separate the aluminum from other materials found in the ore. Then the liquid containing the dissolved aluminum is pumped into tanks where it is cooled, allowing alumina hydrate crystals to form. Those crystals are filtered from the tank and dried in a kiln at approximately 400 degrees Celsius (° C) or 752 degrees Fahrenheit (° F) to produce aluminum oxide.

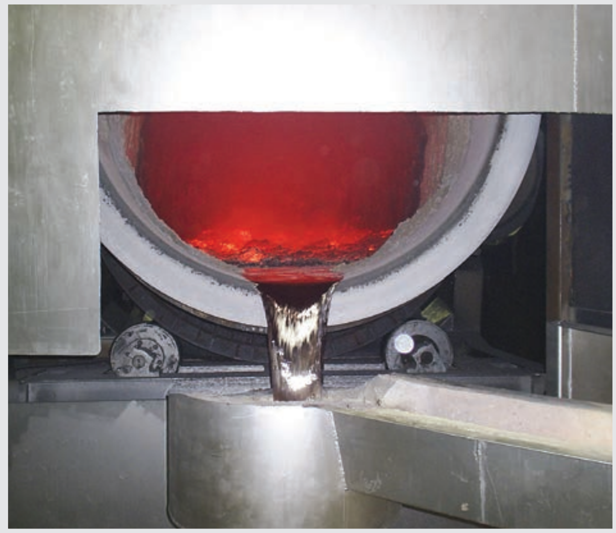
Producing aluminum from the aluminum oxide requires chemical reactions at temperatures of more than 1000° C (1832° F). The aluminum oxide is placed

Life Cycle Information: Cast Aluminum Furniture (2 of 3)

with a carbon rod into a cell where the combination of electricity and high temperatures causes a chemical reaction that produces carbon monoxide, carbon dioxide, and aluminum. The molten aluminum collects at the bottom of the cell where it can be separated from the other materials. Depending on the intended use of the aluminum, it will be mixed with small amounts of other metals to produce the desired characteristics. Such mixtures of metals are called alloys. The aluminum is made into an alloy while it is still in its molten form. The alloyed aluminum is then cast into ingots or billets (terms for rectangular and cylindrical pieces of aluminum alloy).

At this point the ingots of primary aluminum can be mixed with secondary aluminum. Recycling scrap aluminum is a way to avoid the most energy intensive (and costly) steps of aluminum production. Scrap aluminum has already been separated from the impurities in bauxite and converted from aluminum oxide. To process secondary aluminum, scrap aluminum must first be collected. Aluminum can be recycled without loss of quality. This makes scrap aluminum relatively valuable. As a result, collecting and recycling scrap aluminum has become its own sub-industry. Ideally, aluminum is collected in a closed-loop process based on the particular aluminum alloy. For example, soda cans are collected in order to be made into new soda cans. By including only one aluminum alloy in a batch of scrap, manufacturers can be confident that the final product will have the same desired characteristics for that particular use. In other cases, the various scrap aluminum alloys are mixed together.

Once the aluminum is collected, it is shaved into small pieces for processing. Often scrap aluminum has enamel, paint, or some other substance that can reduce the purity of the final product if it is not removed. The aluminum is heated close to the melting point of aluminum (660° C) to remove these substances. The aluminum is then melted down and cast into ingots or billets, similar to the process for primary aluminum, though the aluminum from the mixed scrap may require extra steps before that aluminum is again ready for use. As a result, the production of recycled aluminum results in a 90 percent reduction of greenhouse gas emissions when compared to the production of primary aluminum.



ED MANSELL/OWNER, MANSELL AND ASSOCIATES

Scrap aluminum is melted to remove impurities.

Stage of Life Cycle	*Processing Aluminum (½ Primary and ½ Secondary)*
CO_2 Emissions (kg/set)	187
CH_4 Emissions (kg/set)	0.302
N_2O Emissions (kg/set)	0.266

Manufacturing Furniture

To make cast aluminum, the ingots are melted and poured into molds of the desired shape. Unlike the plastic resin, each mold corresponds to just a part

Life Cycle Information: Cast Aluminum Furniture (3 of 3)

of the actual furniture piece. Once the pieces have been cooled and hardened, any excess aluminum can be removed and recycled. The pieces are then fitted together and welded. The cast aluminum dining set for this project has cushions made from plastic resin, but an alternate aluminum set might contain cotton cushions. Greenhouse gas emissions from the production of the plastic resin for these cushions are also included in the calculations for this step. Still, the bulk of the greenhouse gas emissions from this step result from the energy needed to melt the aluminum for casting.

Stage of Life Cycle	*Furniture Manufacturing*
CO_2 Emissions (kg/set)	108
CH_4 Emissions (kg/set)	0.437
N_2O Emissions (kg/set)	0.000113

Use/Maintenance

Like the plastic resin furniture set, the maintenance of cast aluminum furniture is minimal. Therefore, greenhouse gas emissions resulting from this stage are assumed to be negligible.

Stage of Life Cycle	*Use*
CO_2 Emissions (kg/set)	0.00
CH_4 Emissions (kg/set)	0.00
N_2O Emissions (kg/set)	0.00

Disposal

If processed correctly, aluminum can be recycled over and over again. Also, because of the relatively high value of scrap aluminum, rates of recycling are high. For this study, we assume that all of the aluminum in the furniture set is recycled. Greenhouse gas emissions associated with the collection and processing of recycled aluminum are included in the following table.

Stage of Life Cycle	*Disposal*
CO_2 Emissions (kg/set)	1.76
CH_4 Emissions (kg/set)	0.0000299
N_2O Emissions (kg/set)	0.0000440

Life Cycle Information:

Pine Furniture (1 of 3)

This set of pine furniture is made from slightly more wood than our calculations use because some wood is lost during cutting and sanding. The emissions provided in this section are based on 70 kg for the final product, with adjustments made to account for wood loss at each step. In addition to wood, the furniture has stainless steel bolts that hold it together.

FIFTHROOM.COM

This furniture is made from lumber harvested from pine trees that are grown in the Southeast United States.

Managing Forests and Harvesting Wood

When looking at the carbon dioxide (CO_2) emissions resulting from harvesting wood, it is important to distinguish between CO_2 produced from burning fossil fuels and CO_2 released from wood. The carbon trapped in trees is part of a relatively short biological cycle. Trees live for decades or perhaps centuries, storing CO_2 as they grow. When a tree dies, it decomposes, and the carbon stored in the tree is released to the soil and back to the atmosphere in the form of CO_2. Of course even as a tree dies, other trees are still growing and still absorbing CO_2 from the atmosphere. Therefore, if a forest is managed sustainably—meaning it is harvested no faster than its ability to grow new trees—then the CO_2 released by harvested trees is balanced over time by the CO_2 stored in new trees as they continue to grow. Because this carbon cycle is balanced in this short biological cycle, it is not typically included when calculating CO_2 emissions over time.

However, when we burn fossil fuels, we are taking carbon that has been trapped for hundreds of millions of years and converting that to CO_2. Since the Earth is not producing new fossil fuels at the rate that we are using them, this represents a flow of greenhouse gases into the atmosphere with no way for the carbon to be sequestered or stored at the same rate. Therefore, in this life cycle assessment, we will focus on the greenhouse gas emissions resulting from the use of fossil fuels since sustainably harvested wood is carbon neutral.

Most trees produced for lumber in the southeastern United States are grown on large plantations. In fact, with more than 32 million acres of pine plantations in the Southeast, this region has been called "the wood basket of the world" (Fox, Jokela, & Allen, 2004). Harvesting trees requires fuel for the tools that cut and trim the trees into logs. In addition, fuel is required to transport those logs to a mill. Sustainable management of a pine plantation, however, requires much more than harvesting trees. New seedlings must be produced and planted to replace harvested trees. Fostering the growth of these new trees may require the application of fertilizer and removal of weeds.

The intensity at which pine plantations are managed varies. Plantations are categorized as low, medium, or high intensity based on level of production. Currently, 37 percent of the pine plantations in the southeastern U.S. are managed at low intensity, 58 percent at medium intensity, and 5 percent at high intensity (Mulkey et al., 2008). The level of greenhouse gas emissions varies with the level of intensity. In order to calculate the greenhouse gas emissions that result in this step of the life cycle of our pine furniture set, a weighted average was calculated. The emissions resulting from the production of the amount of logged wood necessary to produce our furniture set are listed in the following table.

***Life Cycle Information:* Pine Furniture** (2 of 3)

Stage of Life Cycle	*Sustainable Wood Production*
CO_2 Emissions (kg/set)	2.84
CH_4 Emissions (kg/set)	0.00245
N_2O Emissions (kg/set)	0.0000352

Lumber Manufacturing

The manufacturing process for lumber starts when logs are moved on to a conveyor belt that takes them into the mill where they are sorted, cut to a desired length, and debarked. The sawdust and bark made during these steps are typically collected and used to power the machinery at the mill. A large band saw cuts the logs into pieces roughly the same size and shape to be sold as lumber. The sawyer takes care to cut the logs so that he or she gets the maximum amount of lumber. These pieces are then trimmed in preparation for kiln drying. Sawdust is again collected for fuel.

At this point in the process, the wood pieces are called "green lumber" because they still have a lot of moisture. Most of this moisture is removed using a kiln, which is fueled largely by the bark and sawdust collected during the other steps of the process. Since the combustion of these wood products mimics the decomposition of wood in a forest, the carbon emitted from this combustion does not need to be included in this assessment.

BOONE VALLEY FOREST PRODUCTS, INC.

This lumber has been processed and is ready for sale.

Once the wood has been dried, it is planed. During this step, the surfaces of the lumber are smoothed and the wood is trimmed again if necessary. Finally, the lumber is sorted by size and quality and prepared for sale. The emissions reported in the following table include those related to energy from fossil fuels necessary for this step.

Stage of Life Cycle	*Wood Processing—Lumber Production*
CO_2 Emissions (kg/set)	5.96
CH_4 Emissions (kg/set)	0.0110
N_2O Emissions (kg/set)	0.0000134

Pressure-Treating Lumber

Lumber designated for outdoor use is typically pressure treated in order to extend the life of the lumber by protecting it from insects and moisture. In a typical pressure-treating process, the lumber is placed in a large horizontal cylinder that is then tightly sealed. Preservative chemicals are pumped into the cylinder. High pressure is used so that the chemicals penetrate the wood. The previous drying process allows the wood to absorb the preservatives more readily.

The emissions numbers provided for this step include direct emissions from the pressure-treatment process as well as emissions associated with the production of the preservative chemicals used during the process. These emissions are listed in the following table.

Life Cycle Information: Pine Furniture (3 of 3)

Stage of Life Cycle	*Pressure Treatment*
CO_2 Emissions (kg/set)	6.17
CH_4 Emissions (kg/set)	0.0143
N_2O Emissions (kg/set)	0.0000741

Manufacturing Furniture

Of the three sets of furniture, manufacturing of the wood set is perhaps the easiest to picture. The treated pieces of lumber are cut to the correct size and shape and sanded smooth. Those pieces are then fastened together with stainless steel nuts and bolts. The production of these fasteners must also be included when considering the emissions associated with this step of the life cycle.

Stainless steel is a combination of iron, chromium, and nickel. Scrap iron can be used. The rest of the ingredients must be mined from the ground and separated from their ores. The ingredients are melted and mixed in an arc furnace at temperatures of more than 1600 degrees Celsius (° C) or 2912 degrees Fahrenheit (° F). The molten steel is then transferred to a refining vessel, where impurities are removed. The steel is then cast and rolled out into flat sheets. The sheets are then cut into the desired dimensions for making screws, nuts, and washers. The combined weight of the screws and other steel pieces in our example furniture set is 1 kg. The combined emissions associated with the production of the stainless steel fasteners and the manufacturing of the wood furniture are provided in the following table.

Stage of Life Cycle	*Furniture Manufacturing*
CO_2 Emissions (kg/set)	5.24
CH_4 Emissions (kg/set)	0.00686
N_2O Emissions (kg/set)	0.0000410

Use/Maintenance

Wood sealer is typically applied to outdoor furniture in order to protect it from potentially damaging environmental conditions, such as sun and rain. For this study, it is assumed that two treatments of sealer are used over the 15-year life of the furniture set. The emissions listed for this section take into account the gases emitted during the production of the wood sealant.

Stage of Life Cycle	*Use*
CO_2 Emissions (kg/set)	4.25
CH_4 Emissions (kg/set)	0.00976
N_2O Emissions (kg/set)	0.0000432

Disposal

Treated wood must be disposed of in a landfill because of the potentially harmful preservative chemicals added to the wood during pressure treatment. Decomposition in a landfill is anaerobic, unlike decomposition of dead wood in a forest. Since no oxygen is present in an anaerobic environment, the chemical reactions taking place produce methane instead of carbon dioxide. This methane would not have been produced under normal forest conditions. Therefore, the methane emissions resulting from the anaerobic decomposition of wood in landfills are included in the emissions figures for this step of the life cycle. Other emissions result from fuels used in the collection of waste and the management of landfills.

Stage of Life Cycle	*Disposal*
CO_2 Emissions (kg/set)	24.6
CH_4 Emissions (kg/set)	1.63
N_2O Emissions (kg/set)	0.0000733

Comparing Outdoor Furniture

NAME GROUP MEMBERS

Instructions: As you listen to the play or to the student presentations, collect information about the following questions.

Plastic Resin Furniture Set

1. What are the basic raw material inputs necessary to produce polypropylene and other plastic resins?

Aluminum Furniture Set

2. When processing aluminum, most of the emissions are the result of which step?

3. How many times can aluminum be recycled?

Pine Furniture Set

4. When calculating emissions over time, why isn't the carbon dioxide emitted from wood burned for power during the manufacturing process included?

Summary

5. Which furniture type would be best for your school? Why?

6. If every school in your state purchased this type of outdoor furniture, what might the short and long-term impacts be?

Greenhouse Gas Emissions Tables

Use the tables below to keep track of the greenhouse gas emissions associated with each step of the life cycle.

Remember: CO_2 = Carbon dioxide CH_4 = Methane N_2O = Nitrous oxide kg = kilogram

Plastic Resin Set

Stage of Life Cycle	CO_2 Emissions (kg/set)	CH_4 Emissions (kg/set)	N_2O Emissions (kg/set)
Oil and Natural Gas Extraction			
Refining Oil/Processing Natural Gas			
Manufacturing Polypropylene			
Manufacturing Plastic Furniture			
Use			
Disposal			
TOTAL EMISSIONS			

Cast Aluminum Set

Stage of Life Cycle	CO_2 Emissions (kg/set)	CH_4 Emissions (kg/set)	N_2O Emissions (kg/set)
Bauxite Mining (for ½ Primary Material)			
Processing Aluminum (½ Primary and ½ Secondary)			
Furniture Manufacturing			
Use			
Disposal (Recycling Aluminum)			
TOTAL EMISSIONS			

Pine Set

Stage of Life Cycle	CO_2 Emissions (kg/set)	CH_4 Emissions (kg/set)	N_2O Emissions (kg/set)
Sustainable wood production			
Wood Processing/Lumber production			
Pressure Treatment			
Furniture Manufacturing			
Use			
Disposal			
TOTAL EMISSIONS			

Global Warming Contribution Calculation

After you have recorded the greenhouse gas emissions from each step and totaled the results, there's still one more step before you can decide which furniture set will have the highest impact on climate change. Not all greenhouse gases are equal. Some gases are able to capture more energy than others. For example, a kilogram of methane in the atmosphere will trap about 25 times more energy over a 100-year period than a kilogram of carbon dioxide. Therefore, it is said to have a global warming potential of 25. When scientists measure the impacts of greenhouse emissions, they often use the term "carbon dioxide equivalents." This is the basic unit for measuring the global warming potential of emissions. Since 1 kg of methane traps as much heat as 25 kilograms of carbon dioxide, that 1 kilogram of methane has a global warming potential of 25 kilograms of carbon dioxide equivalents. Now you can calculate the global warming potential of each of the three furniture sets. Use the following table to calculate the emissions for each dining set.

Calculating the Global Warming Contribution of Greenhouse Gas Emissions

Gas	Emissions (kg)	Global Warming Potential (100-year period)	Carbon dioxide Equivalents (kg CO_2-eq)
Plastic Resin Set			
Carbon dioxide		x 1	
Methane		x 25	
Nitrous oxide		x 300	
		TOTAL	
Aluminum Set			
Carbon dioxide		x 1	
Methane		x 25	
Nitrous oxide		x 300	
		TOTAL	
Pine Set			
Carbon dioxide		x 1	
Methane		x 25	
Nitrous oxide		x 300	
		TOTAL	

ACTIVITY

11 Life Cycle Assessment Debate

After a debate where students compare products, students develop a set of life cycle questions that can be used to guide their consumer choices.

LCA

Subjects
Biology, Environmental Science, Language Arts, Social Studies

Skills
Communicating, Comparing and Contrasting, Systems Thinking

Materials
Student pages (see Activity Webpage link below)

Time Considerations
Two 50-minute class periods and homework

Related Activities
Students should have an understanding of externalities (Activity 9) and life cycle assessment (Activity 10). This activity can be followed with an opportunity to apply the concept of consumer power to climate change mitigation (Activity 12).

Research Connection
Economists are studying how consumer demand influences economic markets and the subsequent impacts of these changes to other systems, such as the environment. To provide a more holistic picture of these relationships, social scientists are exploring human behavior and strategies to nudge people into behaviors that are more environmentally friendly. Some researchers suggest that taking the time to reflect on behavior and making a conscious choice, instead of a habitual purchase, may lead toward purposeful consumption patterns.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section4/activity11

Objectives

By the end of this activity, students will be able to

- identify at least two questions about environmental impacts that are important to ask about a product before buying it, and
- explain how products are rarely either environmentally good or bad but rather are an embodiment of mixed factors and considerations.

Assessment

- Ask students to take notes during the debate, and then ask them to pick one product pair (e.g., paper cups and glass cups) and describe the environmental impacts for each of the five stages of the products' life cycles. They should compare the impacts of the two products and explain which product they think is more environmentally friendly.

Background

Additional background information can be found in the **Section 4 Overview** and in **Activities 9** and **10**.

Life cycle assessments (LCA) do not provide a clear answer of which products are good for the environment and which are not. Each stage in the life cycle can have so many impacts that it may not be clear which of two products is the "winner." For example, in this activity, students will debate whether print books or e-books are more environmentally friendly. If someone values tree ***conservation***, they might choose e-books since one device can hold millions of pages of paper. On the other hand, if someone is concerned about pollution from electronic waste, they may feel that print books are better for the environment. Both perspectives are valid.

Positive and negative impacts are considered when the life cycle of a product is examined. The negative impacts most often are not reflected in the price of a product and are often referred to as negative ***externalities***. For example, during the material extraction phase, ***renewable resources*** are often better for the environment than ***nonrenewable resources*** that will eventually be depleted. A renewable resource is a natural material that can be replenished within the span of a human lifetime.

It is important to recognize that impacts or externalities associated with consumer decisions do not have to be negative. For example, choosing materials made with wood can provide a number of benefits, such as wildlife ***habitat*** and clean water associated with the forest that produced the wood and less carbon ***emissions*** for the product. When a tree is cut down and turned into a product such as a desk, the carbon that was stored in that tree is now stored in the desk. Since the product stores carbon in addition to emitting carbon during production and transportation, the

Students face a lot of choices when they go shopping. Considering the differences between similar products can help them make informed consumer decisions.

overall amount of carbon added to the ***atmosphere*** is lower than it would be for a plastic or metal product. These are all considered positive externalities of choosing a wood product over the more carbon-intensive alternatives.

Consumer decisions have the potential to play an important role in offsetting negative impacts or externalities associated with the products we use every day. While ***climate change*** may not be a key factor currently in the decision-making process for most consumers, more and more people are making informed decisions with regard to ***sustainability*** and ***climate*** issues. As more consumers recognize the benefits of reducing carbon emissions and request alternatives, the production of less carbon-intensive products likely will increase. Consumer behavior affects the demand for these products. In addition, the increased demand is a catalyst for scientists and entrepreneurs to design new products with lower emissions. This scenario helps us imagine how we can collectively create change through our individual actions.

Teaching This Content

The debate format of this activity allows students to develop and use critical-thinking skills. By debating various criteria to assess products, students are invited to develop their own personal rules for making consumer decisions. Through completing this activity, students can make connections between individual actions and their collective future impacts.

When people think of a debate, they often think of people arguing, but a debate can also be a chance for knowledgeable people to exchange information and ideas as part of a decision-making process. The debate in this activity should result in both the audience and participants becoming more informed about consumer choices. Formal debates can be lengthy and require extensive preparation and training in rhetoric (the art of persuasive speaking). For this activity, students participate in a less formal debate; the preparation time is minimal (much of the information they need is provided for them), and there are few rules that govern the actual debate. As the teacher, you have a dual role: debate coach, to help the students prepare for the debate, and moderator, to guide the actual debate.

Getting Ready

The Activity 11 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section4/activity11).

If your students are not familiar with life cycle assessments, you may want to introduce this topic using the LCA and Externalities presentation on the Activity 9 webpage.

Make copies of the three student pages. Each student in the debate groups (Cups, Books, Bottles and Cans, Grocery Bags) should have one Product Information

Systems Thinking Connection

WHEN CHOOSING A PRODUCT, such as a shirt, people typically include several variables including style, quality, and price. In the activities in Section 4, students learn about other variables that are important when choosing a product. Responsible consumers also consider social and environmental impacts associated with the product at each stage of its life cycle. Are the people who made the shirt paid a fair wage? Are the working conditions safe? Did producing it involve harmful chemicals or the production of ***greenhouse gases?*** In a systems thinking context, students learn to expand the boundaries of a ***system*** beyond personal preference to consider broader impacts.

These skills are essential for making informed decisions about the products and services that we buy. However, ***systems thinking*** does not imply any specific opinion about a product. Even the uninformed shopper has to weigh variables related to style, quality, and cost. Is an increase in quality worth the extra cost? Students who include social and environmental impacts associated with a product must examine many more variables as they make their decisions, but, nevertheless, they must exercise judgment in choosing which products fit their own needs and values best.

Card that contains information about the products under consideration. Each student in the class should also receive copies of the Debate Guide and Reflection student pages.

If your students have never conducted a classroom debate, you may wish to help them prepare. More information for introducing your students to the structure of the debate and for moderating the discussion can be found in Part B of Doing the Activity.

Doing the Activity

Part A: Preparing Students for the Debate

1. Start a discussion by asking students what characteristics they and their parents consider when deciding which of two similar products to purchase. For example, how do they choose between two similar food products, two small electronic products, or two sizable purchases, such as a car? Do the types of considerations vary with different products?

2. Explain to students that they will be participating in debates to compare two similar products. Each group will attempt to convince the class of a product's superiority based on the environmental impacts at each stage of the product's life cycle assessment.

3. Split the class into 8 groups and assign a product to each group. Pair groups who have been assigned to parallel products (paper cups and drinking glasses, paperback books and e-books, plastic bottles and aluminum cans, paper bags and plastic bags). Give each student the Product Information Cards for the pair of two products and the Debate Guide student page.

4. Introduce the debate format and guidelines. You may wish to establish some ground rules at this time. Rules can be basic guidelines prescribed by you (e.g., each student should speak during the debate, talk only when it is his or her turn, avoid personal attacks) or can be built collaboratively using input from students (i.e., ask students what rules they think are needed to ensure a lively yet fair debate). Each debate should take approximately 12 minutes and include the following parts:

- Presentation: Each group should take 3 minutes to present its perspective.
- Rebuttal: Each group will respond to each other's perspectives for 2 minutes to answer or raise more questions.

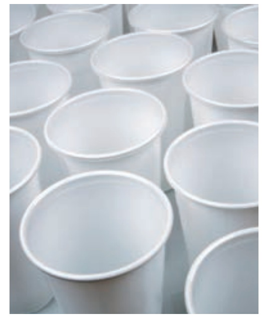
TEACHERS SAY ...

This activity helped my students come up with thought-provoking responses.

—Biology and AP Environmental Science Teacher, Kentucky

In this activity, students debate the environmental impacts of two similar products.

Products Debate



- Summary: Each group will take 1 minute to summarize its main points.

5. Provide time in class for students to prepare for the debate. If your students are not familiar with participating in debates, you may want to cover the following information:

- *Explain the importance of preparation.* Sufficient research is instrumental to a good debate. In this activity, the preliminary research has been done for the students and this information is on the Product Information Cards. Students should thoroughly study their assigned cards. Completing the Debate Guide student page will assist students in understanding and learning the information particular to the product each group will present.
- *Discuss the need to identify both arguments and counter-arguments.* Students should review their completed Debate Guide page and pinpoint the strengths of the product; these strengths will comprise the arguments they will use to garner support for the product. Students in a group should try to guess what the other side (the opposition) will say about both products and be prepared to defend their product and identify weaknesses in the opposition's product. As part of their presentations, groups also may wish to acknowledge the disadvantages of their products and talk about trade-offs involved when selecting a product.
- *Explore the skills of persuasive speaking and good listening.* While solid research is important in a debate, the delivery of that information is also key. Instruct students to avoid personal attacks that can undermine credibility and instead focus on facts and issues. Emphasize the need to listen carefully to all sides as they are presented. If students are too busy thinking about what they will be saying next during the debate, they could miss key points made by the opposition that they need to address. Team members can serve different roles—some can be listening to the other side's presentation while other team members prepare their rebuttal.

Part B: Conducting the Debates

1. Begin the debate by reviewing the debate purpose, format, and rules. At this point, students should be aware of both the purpose of the debate (determining which product is more environmentally friendly based on the product's life cycle) and the structure (12 minutes for each debate), but it is a good idea to present this information again at the beginning of the debates. Students should take notes when they are not actively involved in presenting during the debate. Each student will be asked to summarize information for all debates on the Reflection student page.

2. Flip a coin to decide who goes first and introduce each team just prior to that team's presentation. Based on the debate format, you should guide the sequence of the debate by announcing whose turn it is to speak, how much time they have, and what they may use their time for. In the Paper Cups versus Drinking Glasses debate, for example, your prompts might look like this:

- The Paper Cups team will now present their case. They have three minutes.
- The Drinking Glasses team will now present their case. They have three minutes.
- The Paper Cups team will now have a chance to respond. They have two minutes.
- The Drinking Glasses team will now have a chance to respond. They have two minutes.
- The Paper Cups team will summarize their case. They have one minute.
- The Drinking Glasses team will summarize their case. They have one minute.

3. Keep track of time throughout the debates. You can either assign a student to serve as official timekeeper, monitor the time yourself, or use a timer. If students desire, you can alert the current speaker when there are 30 seconds or 60 seconds remaining.

4. Provide closure to each debate. After the second group in each debate has given its summary, thank the participants for their work and provide quick, positive feedback. You may then introduce the next products to be debated.

5. After all the groups have debated products, lead a class discussion about the debate using the following questions:

- Does anyone agree with the position that they argued in the debate? Did you learn anything new?
- Did anyone change their mind after hearing the debate? What information was convincing?
- Which product do you now favor for each pair? Does context matter? Might you favor one under some circumstances and the other in different circumstances?
- What makes it difficult to decide which product is best?
- Are the negative environmental impacts of your product considered externalities or are they included in the cost of the product? Could they be reduced?
- Sometimes people don't want to hear about the disadvantages of their favorite item. How might you communicate with them?

6. Distribute the Reflection student page to students and ask them to complete the questions for homework. The reflection questions are intended to help them apply what they've learned during the debate and to generalize this information to other products. While there are not specific correct responses, you may wish to check that students don't have inaccurate ideas about evaluating a product. If students are confused about the last question, explain that they may decide what factors in a product's life cycle matter to them as they consider decisions. For example, is a renewable resource important? A recyclable product? A production process that does not use large amounts of energy? Encourage them

TEACHERS SAY ...

My classes are trying to decide how they can use this activity for Earth Day.

—Environmental Science Teacher, Arkansas

Students will use negotiation, critical thinking, and communication skills to debate the pros and cons of different consumer decisions.

to think broadly about these characteristics rather than focusing on a specific product.

7. Systems Reflection: How can debates help improve our systems thinking skills?

Preparing for the counter arguments in a debate is the skill of examining other perspectives, which is an important systems thinking skill. We can investigate perspectives from other people as well as those that we generate ourselves. Systems thinking is a type of critical thinking, and a critical eye can help us consider new aspects of an issue.

8. After distributing the Reflection student page, summarize the activity by reviewing the idea that consumer choices can play a role in reducing and preventing carbon emissions. Students can make more informed consumer decisions by considering the externalities and the environmental issues that can occur as a result of the production, shipping, and disposal of various products. Life cycle assessment can be a helpful tool for comparing similar products. However, consumers are not likely to have life cycle assessment information readily available when making decisions. For this reason, it is important to identify purchasing guidelines, such as the questions and choices that the students develop on their Reflection pages. These questions can serve as a starting point for comparing any set of products and help students in the decision-making process. Remind students that greenhouse gas emissions are only one criterion that can be used to assess products and that they can begin to seek out the various other pros and cons of products before arriving at a personal strategy for consumer decision making.

Modifications

Students may summarize their ideas about common products on posters to help them organize their thoughts before the debate.

Recognizing that products have both significant advantages and disadvantages may be challenging for some students. If you suspect your students will struggle, you might choose to skip this activity.

Consider leading a class discussion rather than have students participate in a debate so you can provide caveats and additional information. You can use the information and questions provided on the student pages to stimulate discussion and reflect upon the impacts of consumer choices. Once students consider a broader range of externalities and factors, their immediate reactions of good and bad products may not withstand scrutiny.

Enrichment

Ask students to consider the questions they generated in response to question 5 on the Reflection student page for a product they want to purchase. Have students write a short essay that describes the product, the questions they asked about the product, and how their responses influenced their intention to buy the product.

Using the Life Cycle Assessment Tutorial located on the Activity 10 webpage, advanced students can conduct a complete life cycle assessment on another pair of products and report on the one that has the lowest emissions and is the most environmentally beneficial.

Additional Resources

Ecolabel Index
Big Room, Inc.
http://www.ecolabelindex.com/
This website provides an informative directory of environment-related product labels from around the world.

Energy-101.org, Units of Measurement
http://www.energy-101.org/did-you-know/units-of-measurement
This website provides videos, definitions, and fun facts about energy. The Units of Measurement webpage may be particularly helpful for students to explore as they prepare for their debate.

International Debate Education Association
http://idebate.org/training/resources/all
This website provides a wealth of teacher resources for holding classroom debates, including demonstrations, how to facilitate classroom debates, post-debate discussion ideas, and debate assessment ideas.

Purchasing Guidelines for the Environmentally Conscious Consumer, CDFS-180-08
Joe Heimlich, The Ohio State University, 2008
http://ohioline.osu.edu/cd-fact/pdf/0180.pdf
This fact sheet provides a general discussion about buying environmentally friendly products and includes a set of questions that consumers can ask before buying a product.

The Noisy Classroom
http://www.noisyclassroom.com
This website provides helpful information for teachers and students on debates, discussions, dialogue, and other speaking and listening activities. In particular, the following webpages can assist students during debate preparation:

- "How Do I Speak for Three Minutes on That?" (http://www.noisyclassroom.com/primary/ideas/how-do-I-speak-for-three-minutes.html)
- "Top Ten Style Tips for Persuasive Speaking (http://www.noisyclassroom.com/primary/ideas/top-ten-style-tips-for-persuasive-speaking.html)

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TEACHERS SAY …

Most students really enjoyed participating in debates, but all students enjoyed watching and listening to them. This activity allows for both. GREAT!

—Middle School Science Teacher, Arkansas

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Product Information Cards: Cups (1 of 4)

Paper Cups

Paper cups are made from trees, a renewable resource. While some paper cups have a small amount of recycled content, most are created from virgin tree fiber, which is harvested from forests using machines that typically run on fossil fuels. Trees are harvested and transported to a paper company that manufactures wood pulp. The pulp is then processed through machinery to make the paper. Paper cups are coated with a thin lining, typically made from polyethylene, which is a type of plastic made from ethane found in natural gas (Packer, 2009). It takes approximately 0.55 megajoules (MJ)* to manufacture a paper cup (Hocking, 1994). They are designed to be disposable and are typically used one time.

The plastic lining keeps the paper from absorbing the liquid, but it also makes the cups nonrecyclable. Therefore, paper cups usually go with trash to a landfill. Landfills have different decomposition rates, depending on sunlight, moisture, and air exposure. In some cases, paper cups can spend more than one hundred years in a landfill due to the lack of water and oxygen needed to breakdown the product. (U.S. EPA, 2011). Though it isn't recommended to drink out of paper cups multiple times (the polyethylene can break down after the first use), used paper cups can have other household uses. For example, they can function as scoops for pet food or containers for sprouting plants for the garden.

Drinking Glasses

Glass is a mixture of sand, gypsum, soda ash, limestone, and dolomite; all are acquired through mining. The raw materials are brought to the manufacturing facility by train, where they are mixed together and melted down to form glass at around 1,649 degrees Celsius (° C) or 3,000 degrees Fahrenheit (° F) (Hess, 2006). The energy to create one glass is approximately 5.5 megajoules (MJ).

Drinking glasses are reusable, and many are used daily for many years. Each time a glass is used, it must be washed, which requires energy and water. Assuming a dishwasher uses 0.18 MJ to wash each glass and that it took 5.5 MJ to manufacture the glass cup, a glass cup must be used 15 times before it becomes as energy efficient as a paper cup (Hocking, 1994). When a person is finished owning a glass it can be donated or sold at a garage sale. Drinking glasses are not accepted at many recycling facilities because of the type of glass used to make them. Therefore, when glasses are broken or thrown away, they often end up in a landfill.

A megajoule (MJ) is a unit of energy that is equal to one million joules. One megajoule is equivalent to the kinetic energy of a one-ton vehicle moving at 160 km/h (mph).

Product Information Cards: Books (2 of 4)

Paperback Books

A traditional paperback book is made from paper, cardboard, ink, and glue. Paper is made from trees, a renewable resource. Most of the wood used by paper companies in the United States comes from privately owned tree farms, where trees are grown, harvested, and replanted. Paper can be made from harvesting whole trees, from wood chips and sawdust that are the byproduct of harvesting trees for lumber or other purposes, or from recycled paper products. The energy used at paper-making facilities usually comes from using the facility's own wood waste, such as sawdust. The paper used to make one book is estimated at two kilowatt hours* of energy (Goleman & Norris, 2010). A papermaking facility produces wastewater that can be a pollutant to local waterways. All water pollution and air emissions are monitored to ensure the facility adheres to current environmental regulations.

Every year, Americans use an average of 700 pounds of paper products, including books, magazines, and newspapers (TAPPI, 2013). The amount of paper that can be produced from one tree depends on many factors. In general, it takes 12 trees to produce one ton, or 2000 pounds, of paper, assuming that none of that paper contains recycled fibers (Conservatree, 2012). This means that one tree makes about 167 paperback books, assuming each weighs about one pound.

An advantage of paper books is that they can be given or sold to others, allowing for a postconsumer market. Some people find value in a book that they can hold, as opposed to a digital book. Depending on how owners treat them, books can last for many years. Books can also be recycled once people are done with them. In 2010, paper and paperboard materials made up 29 percent of the 250 million tons of total municipal solid waste generated in the United States. Approximately 62.5 percent of these materials were recovered through recycling—leaving almost 27 million tons in landfills (U.S. EPA, 2011).

E-book Readers

Electronic books, or e-book readers, are gaining popularity. Depending on the device's memory space, e-book readers can store more than 1,000 books, saving both physical space and paper resources.

Heavy metals used to make e-book readers, such as gold, silver, cadmium, lead, mercury and chromium, must be mined and processed. One e-book reader requires the extraction of 33 pounds of minerals. The facilities that manufacture e-book readers use primarily fossil fuels to power their machines. It takes 100 kilowatt hours* to manufacture an e-reader, which results in the emission of 66 pounds of carbon dioxide (Goleman & Norris, 2010). During the use of the product, consumers can download books automatically, which does not require transportation to a bookstore or library. The device must be charged, which requires household energy.

Used electronics can be passed on to other people. When e-book readers break, they are likely to be thrown away by consumers, leading to toxic metals in landfills. Used electronics are also sent to other countries where workers, including children, dismantle them by hand. In the process, workers are exposed to a wide range of toxic substances (Goleman & Norris, 2010).

****A kilowatt hour is a unit of energy equal to 1000 watt-hours, which is 3.6 megajoules. This is the amount of energy equal to a 40 watt bulb operating for 25 hours, and 100 kilowatt hours of energy could power an average home for three days.***

Product Information Cards: Bottles and Cans (3 of 4)

Plastic Bottles

Plastic bottles are made from petroleum through an energy intensive process that produces carbon dioxide emissions. While some energy is used when the plastic is molded into the bottle shape, the largest amount of energy is used to actually produce the plastic itself (University of Cambridge, 2005). Producing a one-liter bottle, cap, and packaging requires around 3.4 megajoules (MJ)* of energy (Pacific Institute, 2012). Reusing plastic bottles is not recommended, as the plastic can break down over time. Most plastic water, soda, and juice bottles are made from plastic #1, a plastic that is intended for one use, unlike the plastics that are used to create food containers or other reusable plastic items. Plastic #1 is weaker than other plastics and more susceptible to wear and tear, which can cause chemicals to be released from the plastic over time.

Plastic can take hundreds of years to decompose in a landfill. However, many plastic bottles are recyclable. Plastic containers are assigned a number (#1 through #7) based on the type of plastic from which they are made. Most plastic bottles are made from plastic #1, which is recyclable in most areas. In 2010, more than 13 percent of plastic containers—mostly soft drink, milk, and water bottles—were recycled (U.S. EPA, 2011). Recycling uses about 10 percent of the energy that is required to produce one pound of plastic from virgin materials (U.S. EPA, 2002). During the recycling process, the chemical structure of the plastic is altered, so the recycled plastic cannot be remade into plastic bottles. When plastic containers are recycled, they are often made into products such as carpeting, pens, and jackets.

Aluminum Cans

Aluminum is produced by refining bauxite, a mineral ore that contains alumina. It takes four tons of bauxite to produce two tons of alumina. The alumina is then processed into aluminum metal through a smelting process. To produce a 12-ounce aluminum can, 0.81 megajoules (MJ)* of electricity is required. Therefore, it would take approximately 2.82 MJ of electricity to produce enough aluminum cans to hold one liter of liquid. In the United States, most of the aluminum is produced from bauxite imported Japan or Australia (Reynolds Aluminum, 1999).

The entire aluminum can is recyclable—it can be melted down and reused with little loss in quality. In as little as 60 days, aluminum can be recycled and back on the shelf (The Aluminum Association, 2014). In states with can and bottle laws, people pay a small deposit when they purchase a can, which is returned when the can is brought back for recycling. In 2010, the recycling rate of aluminum cans was about 49.6 percent. Recycling one ton of aluminum cans conserves more than 207 million British Thermal Units (BTU), which is the equivalent of 36 barrels of oil or 1,665 gallons of gasoline (U.S. EPA, 2011).

A megajoule (MJ) is a unit of energy that is equal to one million joules. One megajoule is equivalent to the kinetic energy of a one-ton vehicle moving at 160 km/h (mph).

Product Information Cards: Grocery Bags (4 of 4)

Paper Bags

Paper bags are made from cellulose from trees, a renewable resource. Most of the wood used by paper companies in the United States comes from privately owned tree farms, where trees are grown, harvested, and replanted. Paper can be made from harvesting whole trees, from wood chips and sawdust that are the byproduct of harvesting trees for lumber or other purposes. To improve durability and strength, paper bags are typically made from mostly virgin wood fibers, although they can contain various amount of recycled paper materials as well. The energy used at paper-making facilities usually comes from the operation's wood waste, such as sawdust. The facility produces wastewater that can be a pollutant to local waterways. Typically, water and air emissions are monitored to ensure that the facility adheres to current environmental regulations.

Paper bags can be reused by consumers for wrapping packages, as garbage bags, or for holding other items. Paper bags are 100 percent recyclable, and about 10 to 15 percent of paper bags are recycled by consumers (Project GreenBag, 2009). For those bags that end up in a landfill, the length of time it takes for paper to decompose depends on a number of factors, such as temperature, pH, presence of bacteria and nutrients, as well as composition of the paper (Chaffee & Yaros, 2010).

According to a life cycle assessment, the overall energy use to produce 1,000 paper bags that contain 30 percent recycled material is 2,622 megajoules* (MJ) (Chaffee & Yaros, 2010).

Plastic Bags

Plastic bags are made from a material called polyethylene, which is produced from petroleum and natural gas (LaJeunesse, 2004). In 2001, between 500 billion and 1 trillion plastic bags were used worldwide.

Plastic bags can be reused by consumers for a limited number of times. Plastic bags are 100 percent recyclable. In 2010, 12 percent of plastic bags, sacks, and wraps were recycled (U.S. EPA, 2011). The recycled plastic is used to create items such as new plastic shopping bags or outdoor deck material (Progressive Bag Alliance). Many plastic bags (approximately 1 to 3 percent) end up being neither recycled nor put in the trash but become litter that makes its way to rivers, streams, and oceans (Roach, 2003). This litter can impact marine, freshwater, and forest habitats and wildlife.

According to a life cycle assessment, the overall energy use to produce 1,000 plastic bags is 509 megajoules* (MJ) (Chaffee & Yaros, 2010).

A megajoule (MJ) is a unit of energy that is equal to one million joules. One megajoule is equivalent to the kinetic energy of a one-ton vehicle moving at 160 km/h (mph).

Debate Guide

GROUP MEMBERS

Think about the each phase of the product life cycle using the following questions as you read the information for your product. Make sure that you are able to answer each question. Addressing all of these points will make your debate more well-rounded and convincing. Focus on what is environmentally friendly about your product and the shortcomings of the opposing product!

Each debate will last 12 minutes. Each group will have 3 minutes to present its side, 2 minutes to respond to the other group, and 1 minute to summarize main points. You should take notes during the debates you do not participate in.

1. What are the raw materials that go into your product (e.g., trees or aluminum)? How is this material harvested or extracted?

2. How is the product made? How much energy goes into creating it?

3. How many times can the product be used? If it can be reused, does it require inputs such as water or electricity?

4. What happens when the consumer no longer wants the product? Can it be given to someone else? Can it be recycled? Does it go to the landfill or incinerator?

5. What are the key disadvantages to the opposing product that you can use to your advantage?

6. What are the key disadvantages of your product that you should be prepared to defend?

Reflection

NAME

These questions are intended to help you think about, reflect on, and summarize the different stages of the life cycle for **all** the products you learned about during the debate. Provide thoughtful responses based on what you learned during the debate and from your own experiences.

For questions 1 through 4, provide a one or two sentence response. For question 5, respond with one or two paragraphs. Your responses should be broad enough that they can be applied to many products.

1. Thinking just about the *raw materials* that go into a product, what characteristics would make a product more environmentally friendly?

2. Thinking just about *how a product is produced,* what characteristics would make a product more environmentally friendly?

3. Thinking just about *how a product is used,* what characteristics would make a product more environmentally friendly?

4. Thinking just about *how a product is disposed of,* what characteristics would make a product more environmentally friendly?

5. Often when making decisions about what products to buy, we don't have access to information summarizing and comparing product life cycles. However, we still must make decisions for what to purchase. Use your responses from questions 1 through 4 to develop a list of generic questions that you can use in the future to help you decide among any set of products to purchase. Include criteria that would help you favor one product over another.

   In your opinion, what are the most important questions to ask when deciding among products? In your opinion, what factors should weigh more heavily in your decision?

SECTION 5

Solutions for Change

Individual and group actions can create sustainable forests and communities.

WHETHER YOU HAVE USED all of the previous activities in this module or selected a few that are most appropriate for your class, students are likely to need additional time to make connections between these concepts and to reflect on how this information can be used. In addition, many students are most interested in what they can do immediately to address the issue of ***climate change***. This section provides three activities that will help you and your students link concepts together, apply them to local forests, and consider ways to take action.

ACTIVITY 12: The Carbon Puzzle helps students connect the concepts of ***carbon sequestration*** in pine forests, ***carbon storage*** in wood products, and ***forest product substitution***. This activity is based on research that assesses these three ***carbon pools*** to understand how to maximize the removal of atmospheric carbon. It is a good culmination to the ***life cycle assessment*** activities in Section 4 and the carbon sequestration calculations in Activity 8. The activity begins with a review of the ***carbon cycle***, in case you did not use Activity 7. Students are introduced to the concepts through a Six Bits group exercise where they assess a series of facts to answer the following question: How can we best manage planted pine forests and wood to reduce atmospheric ***carbon dioxide***? Afterward, you can walk students through the development of the graph that combines multiple carbon pools using the Tracking Carbon presentation. Students will be able to use this information to answer questions as they interpret the graph. The pilot tests for this activity suggest that conducting the group exercise first makes the topic more interesting and engaging and helps the students better understand the graphing activity.

ACTIVITY 13: Future of Our Forests allows student teams to become experts on one aspect of climate change and forests in the Southeast. Each aspect reflects a component of the module and summarizes the activities they have completed. After researching specific topics, students give presentations to the class and then compile reports, letters, or essays to synthesize their classmates' presentations about the future of southeastern forests. This may be a challenging activity if students have not participated in activities from all the sections. Using the chart provided for this activity, you can reduce the number of student teams to match the activities you have used, though the final summary may suffer from the missing topics.

The activities in this section will help students reflect on what they've learned, link concepts together, and consider ways to take action.

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ACTIVITY 14: Starting a Climate Service-Learning Project provides guidance to plan and complete a service-learning project related to local forests and climate change solutions. Using the knowledge they have gained by completing the module activities, students can work with local resource managers to select a reasonable and useful action for their school or community.

Potential Areas of Confusion

There are several topics in this section that may be sources of confusion for students, based on their existing knowledge, assumptions, or prior experiences. You may be able to use questions to uncover this confusion and steer students toward the clarifications provided in the table.

Key Concepts in This Section

- The impact on atmospheric carbon of substituting a less carbon-intensive product includes the ***carbon savings*** accrued by not using the more carbon-intensive product. Distinguishing between similar products requires that students know which product requires less ***fossil fuel*** to produce or use, avoids generating carbon dioxide, and can be ***recycled*** to reduce carbon emissions.
- Many strategies can be used to enhance forests, mitigate climate change, and adapt to future climate changes. While each of these strategies can be important and appropriate by themselves, they may be more effective when implemented together.
- While there may be many details that people disagree on, they are likely to agree that forests are important to their communities. Maintaining healthy forests is a good goal, and many people can work together to do so.
- Students can make a difference by being leaders in creating positive change within their communities.

Assumption or Confusion	More Adequate Conception
Mitigation strategies through forest management will be a waste if climate change isn't really occurring.	Even without thinking about climate change, most people agree that forests are important and that maintaining healthy and productive forests is a good goal for many reasons. Improving forest health is not a waste.
We can completely reverse or solve climate change with the right solutions.	The residual time for carbon dioxide in the atmosphere leads climatologists to believe that global warming will continue to occur due to recent greenhouse gas emissions even if immediate and significant action is taken to curb these emissions.
If we can implement climate change mitigation strategies, we don't need to worry about adapting to projected changes. Or, if we focus on how to adapt to projected climate changes, we don't need to change our behaviors using mitigation strategies.	Solutions should consider both mitigation and adaptation strategies so that we can reduce climate change impacts as much as possible and prepare for projected changes that cannot be avoided.
Maximizing carbon sequestration depends on keeping trees alive and growing, not cutting them down.	Growing trees is one important way to sequester carbon. However, research indicates that young trees are better able to sequester carbon at a faster rate than mature trees, and wood products can tie up that carbon for a long period of time. For these reasons, continuing to plant and harvest trees for long-lived wood products is a more effective practice to maximize carbon sequestration. Students may have a hard time seeing how cutting trees down can help sequester carbon. It is only when the wood is used for furniture or houses and the forests are replanted that this strategy helps reduce atmospheric carbon.

ACTIVITY

12

The Carbon Puzzle

In this group activity, students assess a series of facts to understand how to manage plantation forests to maximize the removal of atmospheric carbon as they practice cooperative learning and graph interpretation skills.

Subjects
Agriculture, Biology, Environmental Science, Mathematics

Skills
Communicating, Data Analysis, Group Participation, Interpreting Graphs, Organizing Information, Problem Solving, Synthesizing, Systems Thinking

Materials
Student pages, presentation, and answer key (see Activity Webpage link below); scissors

Time Considerations
One or two 50-minute periods

Related Activities
Students should have an understanding of climate change (Activity 2), carbon cycle (Activity 7), and life cycle assessment (Activity 10). This activity helps reinforce and apply these ideas. It can be a culminating activity to the unit, or can be followed by the other activities in this section (Activities 13 and 14).

Research Connection
Scientists are conducting studies to better understand the amount of carbon that is stored in forests and forest products. They are synthesizing research about forest management, the carbon cycle, forest carbon sequestration, and life cycle assessment to understand how forests and wood products can mitigate climate change.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section5/activity12

Objectives
By the end of this activity, students will be able to
- explain the role forests can play in reducing atmospheric carbon through various carbon pools: live trees, dead wood, wood products, and forest products substitution, and
- identify skills that enhance cooperative group work.

Assessment
- Ask students to write a one-page summary that explains the role forests and wood products can play in reducing atmospheric carbon. Students could respond to this prompt by explaining how the carbon pools change over time, resulting in more sequestered carbon.

Background

Across the globe, scientists are investigating how to sequester and store more ***carbon dioxide*** in ***carbon sinks*** such as forests. They are also seeking to understand how to reduce the amount of carbon ***emissions*** by improving efficiency or using less carbon-intensive products. These two lines of actions are related and, in fact, can work together. For example, researchers with the Consortium for Research on Renewable Industrial Materials (CORRIM) have tracked and analyzed carbon across multiple ***carbon pools***. This research ties together several key concepts conveyed in this module: carbon cycles, carbon sequestration, and ***life cycle assessments*** to explore how forests can be managed to reduce atmospheric carbon dioxide.

Carbon Pools

A well-known ***climate change*** solution involves reducing the amount of carbon dioxide in the ***atmosphere*** through ***carbon sequestration*** in forests (see Section 3 for more background information). Trees remove atmospheric

Additional information related to the carbon cycle can be found in the **Section 3 Overview** and **Activities 7** and **8**, and information on life cycle assessment can be found in the **Section 4 Overview** and **Activity 10**.

carbon dioxide and store it in their trunks, leaves, and roots as they grow. Because young, growing trees accumulate ***biomass*** at a faster rate than older trees, they also sequester carbon at a faster rate. Mature trees continue to sequester carbon, of course, but this is balanced by the decay of branches and trees that die. So at the forest scale, additional carbon is not removed from the atmosphere by a mature forest. It does, however, store a lot of carbon in the living trees, dead wood, and soil. The carbon in the dead wood will eventually move to the atmosphere and the soil.

If trees are ***harvested*** for wood products, such as paper or lumber, the carbon in the wood becomes part of these and other products. Paper is a ***short-lived wood product***; the carbon

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Using wood products, which sequester carbon, instead of carbon-intensive products is one way that consumers can reduce atmospheric carbon dioxide.

in these products returns to the atmosphere or soil when they decay or are burned. Lumber, on the other hand, is a ***long-lived wood product***. Depending on how the lumber is used, carbon can stay stored in wood for many years. When forest carbon and wood products are assessed together, sequestration is maximized by growing trees quickly, harvesting before growth slows down, and storing the wood in long-lived products.

Concrete requires cement, and the production of cement generates carbon dioxide from the combustion of fossil fuels and the process of converting calcium carbonate to lime. Currently, our society uses a lot of concrete in building construction around the world.

Forest product substitution is the practice of using wood instead of carbon-intensive nonwood products. For example, lumber can be used instead of other construction materials, such as concrete or steel, to build houses and buildings. Life cycle assessments have shown that producing concrete releases a great deal of carbon dioxide—making it a carbon-intensive product. When using wood, which sequesters carbon, instead of products that cause more carbon to be put into the atmosphere, huge reductions in atmospheric carbon can result. These reductions are referred to as ***carbon savings*** in this activity.

In this activity, students seek to answer this question: How can we best manage planted pine forests and wood products to reduce atmospheric carbon dioxide? The activity will engage students in a discussion about the storage of carbon in live trees, dead wood in the forest, short-lived wood products, long-lived wood products, and forest product substitution. Research shows that reductions in atmospheric carbon dioxide can be maximized by harvesting forests on short rotation cycles so that a constant supply of solid wood products is available to be substituted for carbon-intensive products (Lippke et al., 2010; Perez-Garcia et al., 2005). This research was conducted in the Northwest, where trees are harvested after 45 years for lumber. However, in the Southeast, loblolly pine trees can be harvested for ***lumber*** within 25 to 35 years.

These concepts are introduced in this activity in two ways—through a cooperative learning exercise format known as Six Bits and through a graph that combines all the carbon pools.

Students may recall that ***deforestation*** is one factor that contributes to the increase in atmospheric carbon and may confuse that with forest harvesting. The difference is that a pine ***plantation*** is replanted—this piece of land is always sequestering carbon by growing trees. Deforestation refers to permanently removing forest from the landscape and converting the land into a land-use type that sequesters less carbon (farms or housing, for example). With sustainable ***forest management*** for wood products, forests can be planted, grown, and harvested forever, which enables carbon to be stored both in the growing forest and in long-lived wood products.

Six Bits

In Part A of this activity, students solve a puzzle about how forests, trees, and wood products help remove carbon from the atmosphere. The forests described in this activity are planted pine forests, just like the many southeastern forests that are managed for pulp or timber production. These forests are different from ***naturally regenerated*** or old-growth forests, as the trees in planted pine forests are generally the same age (because they are grown on the same rotation schedule and grow best in full sunlight) and are planted in rows. All privately owned forests are managed according to a landowner's stewardship, economic, or personal objectives.

The Six Bits activity is accomplished by separating the mystery to be solved into small "bits" of information. Students are organized into groups of six where each student is given one of six cards with bits of facts. Card 1 contains the question, and students are asked to work together to answer that question. If students are comfortable working in groups and tackling challenges, they will quickly realize that when they share information on their cards they can collectively determine how it fits together and solve the puzzle. Less adept students, however, may wait to be given more information. You can decide how much to reveal to your students, based on their abilities.

The only rule for the activity, which is written on each card, is that students are not allowed to *show* or *give* their cards to another student. They should, however, verbally share the information on the cards. This guarantees that everyone will be actively engaged in reporting and listening to the information. Note that some students misinterpret this rule to mean that they are not allowed to *reveal* the information on their cards. You can help them understand they are supposed to talk and work together; they can read their cards, but they cannot abdicate responsibility by giving all the cards to one person!

Students who have had practice working in cooperative groups may, on their own, designate a group leader (or perhaps the person with easy access to paper and pencil will become the leader), who will begin to ask group members to identify concepts and report any related facts. You can help students by asking them to choose a leader and a secretary; writing the question on the board to focus everyone on the problem; and suggesting they first ask for all the bits of information related to carbon in trees, then forests, and then carbon in wood products. You may need to explain the concept of substitution (when wood is used instead of a product that has greater carbon emissions during production). It is possible, however, for groups to complete the exercise without additional direction.

Through this activity, students learn not only about forests and carbon but also about the power of cooperation in learning and problem solving. Since each group of six receives the same instructions, the activity wrap-up includes a discussion question about why some groups worked well and others may have stumbled. The importance of identifying a leader, along with leadership and teamwork skills, can be discussed. The Six Bits process models an important societal skill by illustrating how cooperative actions help solve problems and how everyone has valuable knowledge to contribute. In conducting

In this activity, students work cooperatively to solve a puzzle related to climate change and forests. The teachers pictured here are experiencing the activity at a teacher symposium on climate change.

JESSICA IRELAND, UNIVERSITY OF FLORIDA

Systems Thinking Connection

IN THIS ACTIVITY students use a behavior-over-time-graph (BOTG) to explore the relationship between forest management and ***carbon storage***. A BOTG is a common ***systems thinking*** tool to help students understand how different ***stocks*** (or pools) of a ***system*** interact. The key insight here from a systems perspective is that the matter (e.g., the carbon, oxygen, nitrogen) in a forest does not disappear when trees are harvested. Rather, it is incorporated into other stocks.

As children, we are taught to throw trash away. Systems thinking helps reveal that in reality there is no "away" for these things. The Earth is a materially closed system, meaning that except for the occasional meteorite (added material) and some space junk (orbiting and thus temporarily-removed-material), it has the same amount of carbon, nitrogen, and phosphorous today that it had when it was formed roughly 4 billion years ago.

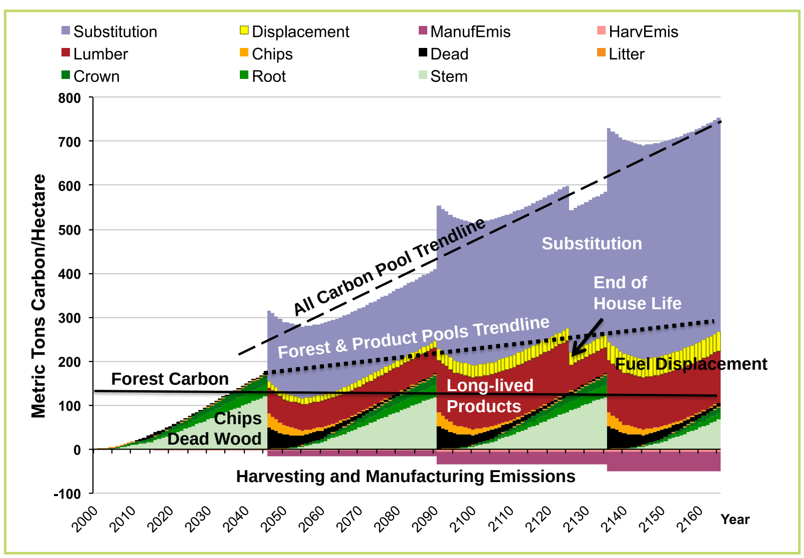
Instructors may want to emphasize the different time scales at which the various stocks are formed. The carbon in the wood stocks (e.g., forest, short- and long-lived wood products) cycles in decades. The carbon saved by not manufacturing energy-intensive concrete, however, will continue to reside in the geological portion of the ***carbon cycle***, where it has been for millions of years.

this activity with your students, you may point out that collaboration works on more than just the classroom level—it may also help people think through issues such as climate change. You may wish to notice if single-sex groups work differently than groups of both males and females, and ask the students why that might be. How does understanding these group dynamics affect how we solve problems?

Combining Carbon Pools in a Graph

To reinforce the answer to the Six Bits puzzle, Part B presents a graph that combines carbon pool data over the course of 150 years (figures 1 and 2). The carbon included in the graph is measured from forests, dead wood, short-lived wood products, long-lived wood products, and carbon saved. As you can imagine, this graph is complex and provides a great opportunity to sharpen graph-reading and interpretation skills. The Tracking Carbon presentation provides a step-by-step explanation of the graph and each carbon pool and how they combine to build the final figure in the teacher notes for each slide. You can use this presentation to guide students through the complex graph and enable them to answer questions as they complete the student page.

Figure 1. The information presented in this activity is based on research that explores how forests, wood products, and wood substitution can reduce atmospheric carbon dioxide (Lippke et al. 2010).



LIPPKE ET AL., 2010

Teaching This Content

This activity helps you summarize the concepts in this module by demonstrating how all of us can contribute to healthy, sustainable forests and communities. Engaging in small group discussions through the Six Bits activity helps your students practice important communication and critical-thinking skills. How might understanding forest management in a changing climate improve your students' abilities to address climate change? By becoming more proficient at understanding and exploring complexity, students will be better able to address complex issues related to climate change through their comprehension of stocks and flows.

This activity supports teachers in developing key knowledge and skills among their students. Part A promotes students' cooperative and communication skills, and Part B gives them practice with scientific instructional representations (i.e., graph). When we pilot tested this activity with teachers, they told us that the puzzle should come first. Even though students may be confused, this is a good way to use curiosity to sustain their attention and interest so they can make sense of the graph.

Getting Ready

The Activity 12 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section5/activity12).

This activity synthesizes information from Sections 3 and 4. It will be beneficial if students have already become familiar with the carbon cycle (Activity 7), carbon sequestration (Activity 8), and life cycle assessment (Activity 10).

Download the Tracking Carbon presentation from the Activity 12 webpage. If you feel you would like more guidance for Part B before using it with your students, an additional narrated version of the Tracking Carbon presentation can be found on the Activity 12 webpage. Make copies of the Six Bits student page, one for each group of six students. Cut each page along dotted lines to form sets of six cards for each group.

Doing the Activity

Part A: Six Bits

1. Remind students of the carbon cycle (see **Activity 7: Carbon on the Move**) and prompt them to list the different ways carbon enters

TEACHERS SAY ...

This was one of the best activities for pulling a lot of the information together.

—Biology Teacher, Kentucky

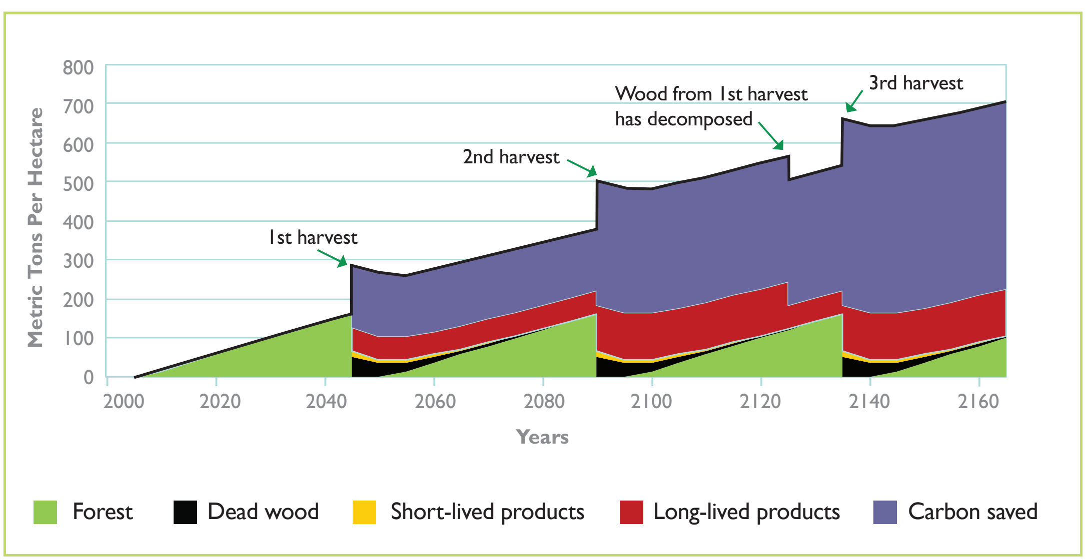


Figure 2. The Tracking Carbon presentation walks students through creating a simpler version of the carbon pools graph.

and leaves the atmosphere. Remind them of life cycle assessment (see Section 4) and ask them where the carbon goes when a tree is used to build a house. Briefly discuss the concepts of forest product substitution and carbon savings; students will learn more about these concepts as they solve the Six Bits puzzle. The introductory slides of the Tracking Carbon presentation provide a brief overview of carbon, the carbon cycle, and the role of carbon in climate change. These slides may be useful if you have not completed Activity 7 with your students.

2. Divide the class into groups of six students. If the class is not evenly divisible, make a few groups with less than six students rather than groups with more than six students.

3. Explain to students that they are going to work in small groups to solve a puzzle related to climate change and forests. Each group will get the same set of six different cards, and each student will get one (or more) of the six cards. One of the cards has the question that the group must answer. Explain to students that every group member has different "bits" of information that are essential to answering the question, so everyone will need to participate. The goal is for students to figure out the information they need, in the order they need it, so that everyone can participate and help answer the question. This teaching strategy engages everyone and reduces the problem of freeloaders in group tasks. You can also challenge groups to see who can finish the puzzle first. Instruct students in the following rules of Six Bits:

- Students are not allowed to *show* their cards to anyone else.
- Students are not allowed to *look* at the cards of other students.
- Students should tell other group members the clues on their card when they are relevant or necessary for solving the puzzle.
- Each group is responsible for answering the question posed on Card 1.

4. Distribute one set of Six Bits cards to each group. Each student should receive one card, face down. Ask students not to look at their cards until instructed to do so. For groups with less than six students, distribute all the cards, but ask for volunteers or select students to receive more than one card so that the group still has all the information needed to solve the puzzle.

5. When everyone has received their cards, ask students to read their cards silently and then work together to share clues and answer the question. Remind them that only one student has the question and the first step will be for that student to read the question to the group. Or, you might ask a student with Card 1 to read the question aloud and write it on the board. Every group is solving the same puzzle, but they will likely use different strategies to do so. Invite them to pay attention to *how* they solve the problem. Provide as little or as much guidance as you wish, depending

TEACHERS SAY ...

The activity was great. I would not be able to use it without first using Carbon on the Move and Counting Carbon. The Six Bits activity was very engaging. This would benefit my AP class as a review just prior to the exam.

—AP Environmental Science Teacher, Florida

Alternative Six Bits Method

If you'd like to provide more structure and guidance to help students with the Six Bits exercise, try this alternative method.

1. Write the question on the board and underline the three main terms: planted pine forest, wood products, and atmospheric carbon dioxide.
2. Ask students to silently read the statements on their card and to categorize them using the three main terms.
3. Next, have students go through each term one at a time and share within their group the statements they included in that category.
4. Then ask students to look at the remaining statements, share them, and help each other build a better understanding of managing a forest for carbon.
5. One or more students should take notes so the group can clarify what they understand about each main term.
6. Then students can synthesize what they have learned to answer the question.

on how comfortable your students are with ambiguity and cooperative tasks (see the Alternative Six Bits Method box on this page).

6. Circulate throughout the room, answering questions and noting how leadership develops, what causes difficulty, and the order in which groups finish. Ask students to let you know when their group solves the puzzle.

7. Once all the groups have solved the puzzle, ask students the question posed by the activity: How can we best manage planted pine forests and wood products to reduce atmospheric carbon dioxide?

8. Have each group of students share their answers to the question. Students should have discovered that reductions in atmospheric carbon dioxide can be maximized by harvesting forests on short rotation cycles of 25 to 35 years so that a constant supply of solid wood products is available to be substituted for carbon-intensive products.

9. Broaden the discussion to talk about how students solved the puzzle, using these questions as a guide.

- Who took a leadership role in your group? What skills and resources did that person have?
  Leadership may manifest itself in many ways during a Six Bits activity. It could be that a person with the insight to ask everyone else questions is the one who gets the ball rolling to solve the puzzle. It could be the person who has a pencil and is able to take notes.
- Did everyone participate equally? What prevented or encouraged equal participation?
  For example, it could be the gender ratio in a group either favors or hinders group cooperation. Personality may also play a role with more talkative individuals participating more. Did they invite quieter students to contribute?
- How effectively did the group function? What might have improved efficiency? You may ask the group that finished first how they solved the problem so quickly.
- What skills were used to complete this task as a group?
- What different strategies helped some groups solve the puzzle?

10. Discuss with students the advantages of group collaboration. You may ask if they enjoyed depending on each other for information, or whether they were frustrated because they couldn't work by themselves. Most real-world situations require cooperation between parties with different interests, including climate change and forest management issues. Learning how to effectively utilize the skills and knowledge of all participants is in the best interests of everyone.

Part B: Combining Carbon Pools in a Graph

1. Explain to students that the answer to the Six Bits puzzle can also be displayed visually, through a graph that combines carbon pool data over 150 years. Use the Tracking Carbon presentation to guide students through the data regarding each carbon pool and how those data can be combined to provide a more complete view of carbon sequestration. The teacher notes included in the presentation provide an explanation for each carbon pool as well as for how to build the final figure.

2. Once you have gone through the presentation with the students, display the last slide, which shows the combined data from all carbon pools, and ask students to answer the questions on the Combining Carbon Pools student page. An answer key is available on the Activity 12 webpage.

3. Review the correct responses as a class to ensure student understanding.

In addition to the **Tracking Carbon** presentation that you can use with students, the Activity 12 webpage includes a narrated Teacher's Guide to help you better understand how to explain the graph.

4. Systems Reflection: How does studying a behavior-over-time-graph help promote systems thinking?

Behavior-over-time-graphs are tools to help people understand systems as dynamic rather than static. By providing a picture of how multiple variables in a system are changing over time, they allow people to better understand the patterns involved in those changes and the relationships between the variables over a certain period of time.

5. Summarize Part A and Part B of this activity by reminding students of the role of carbon pools and fluxes within an ecosystem and by synthesizing information about forest management, the carbon cycle, carbon sequestration, and life cycle assessment. How can plantation forests be managed to maximize productivity in a changing climate? How might the concepts of carbon pools and fluxes play a role in consumer decisions when considering climate change mitigation? Should we use policy to influence markets to encourage people to use wood products?

Modifications

You may wish to simplify this activity, particularly if your students struggle with understanding and interpreting data through graphs. In this case, you may wish to complete just Part A of this activity. The first half of the Tracking Carbon presentation will still be useful if you choose to do this modification. If students are struggling to solve the Six Bits puzzle, consider a "Team Six Bits" activity. To do this, divide your class into six groups and give each group of students one of the Six Bits cards. Then, students can work as a class to solve the puzzle.

Enrichment

Have students read the CORRIM fact sheet (available at http://www.corrim.org/pubs/factsheets/fs_05.pdf), which includes other carbon pools not covered in this activity. You can then lead a class discussion using the following steps:

- Ask students what those other pools represent and how each new pool affects the numbers regarding carbon sequestration.
- Help students discuss the strategies that can be used to reduce atmospheric carbon by asking them to categorize the carbon pools discussed in this activity. First, as a class, list possible carbon pools. Then ask students to place the various carbon pools into groups based on whatever criteria they like.
- Have the students describe their chosen groupings in class. Possible groupings include human-made (short-lived and long-lived wood products) versus natural (forest, dead wood). The substitution pool may not fit well with the other groups. It's fine to leave it on its own. Other groupings may be based on the length of time the pool is intact with short-lived pools (dead wood and short-lived products) in one pool and long-lived pools (forests, long-lived wood products) in another. If students do not mention this distinction on their own, be sure to emphasize it for them.
- Wrap up the discussion by reminding the students that the substitution pool involves carbon that has not been in the atmosphere for millions of years.
- Ask students to graph the carbon pools in a cornfield or a forest that is cleared for urban development. They should be able to select the pools and graph them to indicate relative amounts.

Additional Resources

CORRIM Presentations
Consortium for Research on Renewable Industrial Materials (CORRIM)
www.corrim.org/presentations/index.asp
This portion of the CORRIM website provides several videos and presentations related to assessments of carbon storage, life cycles, and product substitution.

Forests for the Next Century
http://rethinkforests.com/
This website has information and several videos related to forest health, climate change, and carbon sequestration in wood products.

Forest Management Solutions for Mitigating Climate Change in the United States
Robert W. Malmsheimer et al., 2008
www.ntc.blm.gov/krc/uploads/399/Forest%20Management%20Solutions%20 for%20Mitigating%20Climate%20Change.pdf
This *Journal of Forestry* article contains an executive summary and chapters related to preventing greenhouse gas emissions through wood substitution and biomass substitution, as well as information about reducing atmospheric greenhouse gases through sequestration in forests and storage in wood products.

Maximizing Forest Contributions to Carbon Mitigation
Consortium for Research on Renewable Industrial Materials (CORRIM), 2009
http://www.corrim.org/pubs/factsheets/fs_05.pdf
This fact sheet summarizes CORRIM research findings for life cycle assessment studies related to carbon in forests, forest products, and wood product substitution.

Towers of Steel? Look Again
Henry Fountain, The New York Times, September 23, 2013
http://www.nytimes.com/2013/09/24/science/appeal-of-timber-high-rises-wid-ens.html?pagewanted=all
This newspaper article reports on how some architectural firms are exploring the use of timber, rather than steel and concrete, to build skyscrapers that sequester carbon.

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Lippke B., Wilson, J., Meil, J., & Taylor, A. M. (2010). Characterizing the importance of carbon stored in wood products. Wood and Fiber Science, 42 CORRIM Special Issue: 5–14. Retrieved from http://www.corrim.org/pubs/reports/2010/swst_vol42/5.pdf

Perez-Garcia, J., Lippke, B., Comnick, J., & Manriquez, C. (2005). An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. *Wood and Fiber Science, 37 Corrim Special Issue:* 140–148. Retrieved from http://soilslab.cfr.washingtonedu/Publications/Perez-Garcia.pdf

Six Bits

Instructions: For each group of six students in your class, make one copy of this sheet. Cut the six cards along the dotted lines. Distribute a set of cards for each group—one card per person for each group of six. Remind students that they cannot show their cards to each other, but they should share the information verbally.

Card 1

Do not show this card to anyone in your group. You may read the information on the card to your group.

- How can we best manage planted pine forests and wood products to reduce atmospheric carbon dioxide?
- Fertilizer application helps trees grow faster.
- Forest product substitution is the practice of using wood instead of other products.
- Lumber is a long-lived, solid wood product; the carbon can stay stored in wood for many years, depending on how the lumber is used.

Card 2

Do not show this card to anyone in your group. You may read the information on the card to your group.

- Substituting wood products for more carbon-intensive products leads to additional reductions in atmospheric carbon dioxide.
- For buyers to choose lumber over concrete, lumber must be available and sold at a competitive cost.
- Growing trees faster is one way to sequester more carbon.
- After trees are harvested, carbon in the wood can be stored in forest products, such as paper and lumber.

Card 3

Do not show this card to anyone in your group. You may read the information on the card to your group.

- Forest product substitution is a carbon pool.
- Trees that grow on pine plantations are harvested for forest products.
- The average useful lifespan of a wood house is 80 years.
- Harvest cycles of 25 to 35 years provide a steady supply of solid wood products.

Card 4

Do not show this card to anyone in your group. You may read the information on the card to your group.

- As trees grow, they remove atmospheric carbon dioxide and store it in their trunks, leaves, and roots.
- Recycling paper is one way to keep carbon out of the atmosphere.
- Lumber can be used instead of other construction materials, such as concrete or steel, to build houses and buildings.
- Young, growing pine trees up to about 25 years old sequester significantly more carbon than mature trees.

Card 5

Do not show this card to anyone in your group. You may read the information on the card to your group.

- Forest carbon (stored in trunks, leaves, and roots) is an important carbon pool.
- Concrete and steel production release a great deal of carbon dioxide—making these products carbon-intensive.
- For landowners to manage their forests for lumber, there must be a market to sell their wood.
- Mature southern pine trees over 40 years old maintain the carbon they have sequestered, but do not add a lot of additional carbon.

Card 6

Do not show this card to anyone in your group. You may read the information on the card to your group.

- Paper is a short-lived wood product; the carbon in these products returns to the atmosphere when they decay or are burned.
- When only considering the forest carbon pool, carbon storage is maximized by maintaining old, mature trees.
- Life cycle assessments of concrete and wood reveal that concrete contributes significantly more atmospheric carbon than wood.
- Forest products (such as lumber and paper) are an important carbon pool.

Combining Carbon Pools (1 of 2)

NAME DATE

Based on the discussion about the carbon pools and using the graph of data from those pools (see page 2 of this handout), answer the following questions.

1. Where does the carbon come from when trees grow?

2. When the forest is cut (years 2045, 2090, and 2135), which carbon pools decrease immediately? Which carbon pools increase immediately? For each carbon pool, explain why it increases or decreases.

3. What happens immediately to the total carbon (represented by the black line that follows the top edge of the colored area on the graph) during the years that trees are harvested? Explain why in terms of your answer to Question 2.

4. What happens to the total carbon sequestered during the decade after each harvest year (2045–2055, 2090–2100, and 2135–2145)? Explain this behavior in terms of the carbon pools.

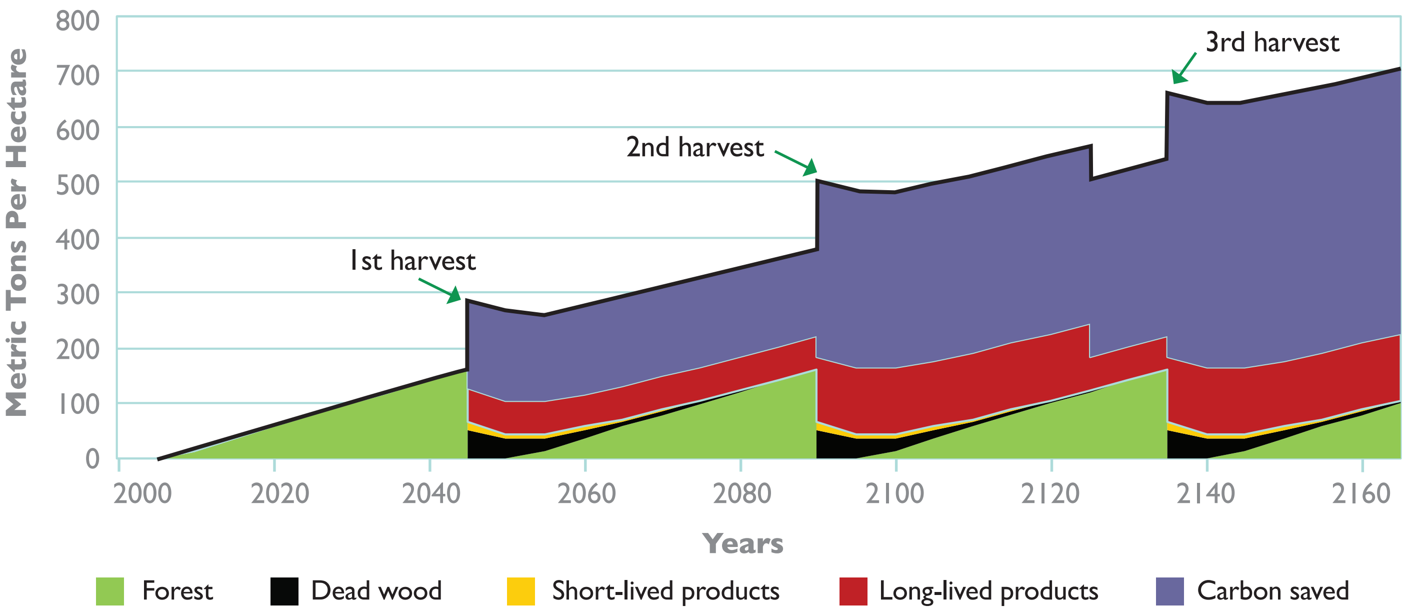
5. What happens to the total carbon sequestered at year 2125? Which carbon pool is responsible for this behavior? Explain why this carbon pool changes during this year.

6. Describe the carbon-saved pool. Why is this the biggest component on the graph? If it is so much bigger than the forest pool, can we obtain these benefits without the forest carbon pool?

7. Which carbon pools tend to grow over time and which ones are cyclical, rising and falling over time? What insights about carbon sequestration does this provide?

Combining Carbon Pools (2 of 2)

Forest + Dead Wood + Short-lived Products + Long-lived Products + Carbon Saved Pool



ACTIVITY

13 Future of Our Forests

Student teams review what they have learned in this module by compiling a report on the future of forests in Southeast United States. Students can share their knowledge by writing a letter to their state or county forester, city arborist, local newspaper, community leaders, or other audiences that are relevant in your area.

Subjects
Agriculture, Biology, Environmental Science, Language Arts

Skills
Analyzing, Communicating, Critical Thinking, Predicting, Researching, Synthesizing

Materials
Student pages (see Activity Webpage link below); Internet access

Time Considerations
Two 50-minute periods

Related Activities
Students should have an understanding of at least two concepts introduced in this module. See the chart in Getting Ready to review how to adapt the activity to review what you have covered.

Research Connection
Scientists around the world are exploring the process of climate change and the opportunities we have to mitigate and adapt.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section5/activity13

Objectives
By the end of this activity, students will be able to
- synthesize information about the forest and climate system, and
- communicate recommendations for forest managers about adapting to future climate uncertainty.

Assessment
- Use the handouts and summary reports to assess how well students understand the connections between climate, forest, emissions, and consumer choice.
- Ask students to write an essay in response to the prompt: Describe at least two ways in which climate change may affect forests in your area and how this might impact landowners in your community. Describe at least two strategies that people could do to either reduce or cope with this potential impact.

Background

Forests in the southeastern U.S. are very important resources. While these forests account for only 2 percent of the world's total forest cover, they produce 16 percent of its ***timber*** products. Forestland also protects watersheds, provides wildlife ***habitat***, and offers outdoor recreation experiences for people. Healthy, ***resilient*** forests are important to the future of the Southeast, the nation, and the world.

The other activities in this module introduce students to the potential impacts of ***climate change*** on southeastern forests, the research underway to understand these changes and develop strategies to protect forest resources, the management possibilities that could reduce atmospheric ***carbon dioxide*** and increase resilience of forests, and the role that consumers could play in making choices that emit less carbon and in encouraging wood substitution to sequester carbon.

Additional background information can be found throughout the module.

You can help students synthesize this information and understand how each section of this module contributes to the future of southeastern forests by asking teams of students to summarize key points related to one topic in a one-page handout and short presentation. Group assignments are based on using several activities in this module. If you have not had time to use them all, you may need to change the group assignments to reflect the activities you have completed. You may want to remind students of which activities they completed by reviewing the associated background readings and slide presentations in this module. In addition, the cards on the Group Assignments student page can be a starting point for each group's research. After hearing from each group, ask students to write a summary report, essay, or letter for the

STEVE MCKEAND, NORTH CAROLINA STATE UNIVERSITY

This activity provides an opportunity for students to summarize the concepts they've learned about climate and forests.

state or county ***forester***, city arborist, local newspaper, community leaders, or other audiences that are relevant in your area.

Teaching This Content

Learning occurs when we provide opportunities to experience *and* reflect. This activity gives students a chance to return to information they learned in this module and put the pieces together for themselves and others. The act of recalling information may reveal misconceptions that were not effectively reconstructed and facts that were not retained. You can help students realize their questions and support them in digging up additional information. If they have identified the gaps in their knowledge, they may be more likely to remember the information they find to fill those holes.

Systems Thinking Connection

AS STUDENTS PREPARE handouts and presentations for the class, instructors may want to remind them to incorporate the systems thinking concepts that they have been learning as well. At what scale are they exploring the system? Where are they drawing the system's boundary? What are the important variables? What is the relationship between the variables? Are there connections that are often overlooked? Are these connections direct or indirect? Are there any delays between the causes and the effects? What are the feedbacks within the system?

When groups begin to synthesize all of the information and communicate it to others, they help the audience understand the system. What will make it easier for people to understand how the pieces fit together and interact? Students might find an analogy or example will be helpful. How does their group topic fit into the larger picture? What are the connections to concepts and topics covered by other groups? It might even be useful for students to tell the audience that they are describing a system and then define its variables, relationships, and boundaries.

Getting Ready

The Activity 13 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section5/activity13).

Select the Group Assignments cards you need based on the following chart. Note that in addition to this activity, Activities 9, 11, and 14 are not included on the chart. Adjust the questions on the Reflection student page to match the groups you have chosen. Make copies of student pages and cut the cards you will need for your groups.

Review the information on the selected Group Assignments student page and locate the background information, videos, or presentations from activities in this module that you need to provide for each group.

Doing the Activity

1. Divide the class into equal groups based on the number of role cards that you can use (which is based on the activities you conducted from this module). Each group will need to ac-cess websites, videos, and background informa-tion associated with the information on their card. Provide a copy of the Reflection student page to each group member so students can develop summary answers to the questions related to their topic.

2. Invite each group to review the data, summarize the information in a one-page handout, and make a presentation to the class with findings and synthesis. The reports should include at least three supporting references.

3. As students listen to the group presentations, ask them to complete the Reflection student page.

4. After all groups have presented, discuss the following questions as a class:

- What are some general trends for how climate change might affect forests in your area?
- How can forests help reduce atmospheric carbon dioxide?
- What can forest landowners do to reduce risks associated with climate change?
- What can consumers do to reduce carbon dioxide added to the atmosphere through human activities?
- What information will help people understand and act on these concepts?

5. After hearing the presentations and collecting the handouts, ask each group of students to write a summary report, essay, or letter to

If your class experienced **this activity. . .**	You can use **this card . . .**
1: Stepping through Climate Science	Climate Scientist Group, Forest Ecologist Group
2: Clearing the Air	Climate Scientist Group
3: Atlas of Change	Climate Scientist Group, Forest Ecologist Group
4: The Changing Forests	Forest Ecologist Group, Forest Researcher Group
5: Managing Forests for Change	Forest Ecologist Group, Forest Manager Group
6: Mapping Seed Sources	Forest Manager Group, Forest Researcher Group
7: Carbon on the Move	Tree Biologist Group
8: Counting Carbon	Tree Biologist Group
10: Adventures in Life Cycle Assessment	Forest Industry Group
12: The Carbon Puzzle	Forest Manager Group, Forest Industry Group

EVAN CANTWELL, GEORGE MASON UNIVERSITY

In this activity, students work in groups to compile a report on the future of southeastern forests.

explain the importance of forests, how forests are likely to be impacted by climate change, and what landowners and citizens can do to mitigate the effects of climate change and protect the health of southeastern forests. As a class, select the audience(s) for these documents. For example, you may wish to communicate this information to the state or county forester, city arborist, local newspaper, community leaders, parents, or other members of the community. You could choose to share all of the reports with one audience or have different groups write for different audiences.

6. Systems Reflection: Use the questions in the Systems Thinking Connection box to prompt student discussion and to reinforce important systems concepts, such as scale, boundaries, direct and indirect impacts, and time delay.

7. Summarize this activity by helping students see the system and the connections between climate change, forest management, industrial wood production, and consumer choices. In sum, students may gain hopeful strategies for adapting to and perhaps even mitigating climate change. Sharing what they have learned with others will help students learn the information and gain a sense of worth: they are helping to bring these strategies to those who can use them. They are making a difference!

Modifications

Adjust the Group Assignment Cards to reflect the activities you conducted with your class and ask each group to tell a story, perform a skit, write a handout, or make a presentation that conveys what they learned. The synthesis product may be designed to answer this question: What should people know about forests and climate? This can be shared with other students or parents.

Enrichment

Ask a local forester or forest landowner to visit your classroom to listen to the student presentations. This person could share knowledge about the topics being discussed and also share career information with students.

Allow students the opportunity to give their presentations as part of a Climate Change forum open to the public or at another appropriate event.

Additional Resources

Southern Forest Futures Project
U.S. Forest Service
www.srs.fs.usda.gov/futures
This website provides summary reports, a webinar, and other resources related to a multiyear research effort that forecasts changes in southern forests between 2010 and 2060.

Southern Forests for the Future
World Resources Institute
www.seesouthernforests.org
This website contains maps, photos, case studies, and other information to highlight key features and trends for southern forests.

Group Assignments (1 of 3)

Climate Scientist Group

YOUR TASK: As a group, create a 5- to 10-minute presentation and one-page handout to explain why scientists believe that humans are impacting the climate and focus on the types of changes that will affect your state.

You can start your research with the following websites and documents:

- **TACCIMO Climate Report** (www.sgcp.ncsu.edu:8090/about.aspx): Under the *Generate a Report* tab, click *Climate Report* and select your state. This report will contain a range of potential future climate projections represented by different combinations of global climate models and scenarios.
- **NOAA Climate** (www.climate.gov): This website provides information, maps, and videos to help you understand climate science.
- **Climate Change: Evidence, Impacts, and Choices** (http://nas-sites.org/americasclimatechoices/more-resources-on-climate-change/climate-change-lines-of-evidence-booklet): This booklet explains climate change, impacts expected in this century, and how science can inform management and reduce risks. At this site, you can also find a video and figures to help with your presentation.
- **Climate Change: Evidence and Causes** (http://www.nap.edu/catalog.php?record_id=18730): This short booklet provides clear answers to 20 common questions and background basics to climate change science.
- **NASA Global Climate Change** (http://climate.nasa.gov): This website provides information on the evidence, causes, effects, and uncertainties of climate change. There is also recent data on global temperature, carbon dioxide levels, and the rate of sea level rise.

Forest Ecologist Group

YOUR TASK: As a group, create a 5- to 10-minute presentation and one-page handout to build on the Climate Scientists' summary and apply these projected climate changes to forests. Which changes are likely to affect the forests in your state? How? What types of changes could people experience?

You can start your research with the following websites and documents.

- **Climate Change, Forest Impacts and Adaptation** (www.epa.gov/climatechange/impacts-adaptation/forests.html): This website discusses the impacts of climate change on forests and productivity as well as the role of disturbances.
- **Earth & Sky, Neil Sampson Says Climate Change Speeding Flux of Forest Ecosystems** (http://earthsky.org/earth/climate-change-speeding-flux-of-forest-ecosystems): During this 90-second interview, scientist Neil Sampson describes how forests may be affected by climate change.
- **Forests and Global Climate Change: Potential Impacts on U.S. Forest Resources, Section 2 of Report, Ecological Impact** (www.c2es.org/docUploads/forestry.pdf): This report discusses the link between climate change and ecosystem shifts. Both past and projected changes are considered.
- **Tree Atlas** (www.nrs.fs.fed.us/atlas/tree): This site includes information about climate models and projects how forest ecosystems in the eastern U.S. might fluctuate as the climate changes.

Group Assignments (2 of 3)

Forest Manager Group

YOUR TASK: As a group, create a 5- to 10-minute presentation and one-page handout about managing forests under changing climate conditions. What exactly should forest landowners do to protect and conserve their forest resources? Why?

You can start your research with the following websites and documents.

- **Southern Forests for the Future** (www.seesouthernforests.org): This website contains maps, photos, and information you can use in your presentation.
- **Protecting Your Forest Asset: Managing Risks in Changing Times** (http://www.pinemap.org/publications/fact-sheets/Protecting_Your_Forest_Asset.pdf): This pamphlet reviews healthy forest strategies and approaches to decrease the risks associated with projected climate change impacts.
- **Southern Group of State Foresters** (www.southernforests.org): This website provides links to explore your state forest agency's website to learn about forest management.

Forest Researcher Group

YOUR TASK: As a group, create a 5- to 10-minute presentation and one-page handout that provides insights into the many ways researchers are helping managers improve southeastern forests.

You can start your research with the following websites and documents.

- **State Climatologist Interview with NC People** (http://video.pbs.org/video/2134881398/?starttime=671000): This video is an interview with the North Carolina State Climatologist to explain how climate impacts forests in the region.
- **The Forest Service and Climate Change** (www.fs.fed.us/video/climate): This video introduces climate change science, impacts on forest ecosystems, and how the U.S. Forest Service is responding to climate change.
- **PINEMAP** (http://pinemap.org): This website contains research summaries, newsletters, photos, and videos that describe current research related to pine plantations and climate change in the Southeast.
- **WaSSI** (http://www.forestthreats.org/research/tools/WaSSI): This web-based tool provides information about how changes in precipitation and temperature may affect water resources and forest ecosystems at the regional watershed level.

Group Assignments (3 of 3)

Tree Biologist Group

YOUR TASK: As a group, create a 5-to 10-minute presentation and one-page handout about the carbon cycle and how trees sequester carbon. Your group can discuss the estimated levels of carbon sequestration that can be expected from maintaining the productivity of forests in the Southeast and planting trees on less productive agricultural land. Your group can also discuss the effect of higher carbon dioxide levels on tree growth.

You can start your research with the following websites and documents.

- **Earth & Sky, Greg McPherson's Tree Carbon Calculator** (http://earthsky.org/earth/greg-mcphersons-tree-carbon-calculator): Scientist Greg McPherson talks about a tool he developed to help determine how much carbon a tree sequesters and the value of knowing this information.
- **The Carbon Cycle** (http://earthobservatory.nasa.gov/Features/CarbonCycle/): This website contains an overview of the importance of carbon and the carbon cycle.
- **I-Tree** (http://www.itreetools.org/index.php): This website provides information on the benefits provided by urban trees.
- **Carbon Dioxide and Future Forests** (http://ns.umich.edu/new/releases/8614): This article from the University of Michigan discusses the effect of higher levels of carbon dioxide and ozone on tree growth.
- **Tree Growth Spurt** (http://www.nytimes.com/2010/02/02/science/earth/02trees.html?_r=0): This *New York Times* article provides information on recent research about growth spurts in trees due to increasing levels of carbon dioxide in the atmosphere.

Forest Industry Group

YOUR TASK: As a group, create a 5- to 10-minute presentation and one-page handout about how forest products play a role in reducing atmospheric carbon. Your group is part of a company that produces a variety of products from forest resources—particularly lumber, OSB (oriented strand board), and plywood. These products sequester carbon, and when consumers purchase them, the carbon stays sequestered for the lifetime of the product. Even more carbon emissions can be eliminated if these products were purchased instead of similar products that rely on fossil fuels or limestone for production (such as those made from concrete or steel). You can explain the life cycle assessment of wood products and how using wood can be a valuable contribution to mitigating the effects of climate change.

You can start your research with the following websites and documents.

- **Consortium for Research on Renewable Industrial Materials, CORRIM** (http://www.corrim.org): This website provides fact sheets, videos, and other resources. In particular the *Editorials* (under *Publications* tab) provide helpful information for your presentation.
- **The Carbon Cycle Poster, The Forest Foundation** (http://www.calforestfoundation.org/pdf/carbon-poster.pdf): This poster highlights the role of forests and wood products in the carbon cycle.
- **Forest Carbon Management: Let's Brainstorm the Tradeoffs** (http://www.treehugger.com/corporate-responsibility/forest-carbon-management-lets-brainstorm-the-trade-offs.html): This website provides information about carbon sequestration in forests and carbon pools.

Reflection

NAME DATE

As you follow along with the group presentations, answer the following questions on this worksheet. Also, make sure to write down information that you think will be important to include in your summary letter.

1. Climate Scientist Group: How are temperature and precipitation projected to change in your state?

2. Forest Ecologist Group: How can these projected changes in climate affect forests in your state?

3. Forest Manager Group: What management strategies should forest landowners use to protect and conserve forest resources? Why?

4. Forest Researcher Group: Describe current research being conducted to help foresters improve the productivity and resilience of forests in the Southeast.

5. Tree Biologist Group: How can forests reduce atmospheric carbon dioxide?

6. Forest Industry Group: What is life cycle assessment and how can life cycle information help us reduce atmospheric carbon dioxide?

ACTIVITY

14 Starting a Climate Service-Learning Project

Students use the knowledge gained throughout this module to plan and complete a climate service-learning project related to forests in their community.

Subjects
Agriculture, Biology, Environmental Science, Social Studies

Skills
Communicating, Defining Environmental Issues, Evaluating, Investigating, Planning, Problem Solving, Working in Groups

Materials
Student pages (see Activity Webpage link below); other materials dependent on project

Time Considerations
Varies, dependent on project

Related Activities
This activity helps culminate your unit on forests and climate. Students should have an understanding of how forests affect and are affected by climate change (Activities 1, 3, 4, 5, 6, 7, or 8) and what people can do (Activities 2, 9, 10, 11, 12).

Research Connection
Student class projects have been found to increase interest and motivation in school and improve academic performance in standard subjects. Students gain problem-solving and critical-thinking skills and may develop a more nuanced and mature view of their communities when engaged in authentic action projects and research.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section5/activity14

Objectives

By the end of this activity, students will be able to

- identify at least two feasible projects they can do to address forest health and climate change, and
- explain the value of individual and community action to promote environmental quality and community wellness.

Assessment

- Ask students to write one or two paragraphs describing the need for the project based on the data collected and how the proposed project will meet the identified need.
- Once the project is complete, ask students to respond to the following prompts: (1) evaluate the effectiveness of the project based on the criteria they identified in the plan, (2) describe intended and unintended consequences of the project, (3) reflect on ways the project could be more effective by providing either next steps or tips for others trying to do a similar project.

Background

Congratulations! You have taught your students a number of key concepts about the future of forests in the Southeast United States, including the role of forests in ***climate change***, the ***carbon cycle*** and ***carbon sequestration***, ***forest management*** strategies, and the role of consumer choices in climate change through ***life cycle assessment*** and product comparisons.

Now what? Your students can apply what they have learned in this module to establish a climate-related action project. Service-learning projects engage students in tackling an issue or problem with the goal of improving their community. Projects can be related to many topics and be implemented in many ways. For this activity, the projects should relate to improving nearby forests and/or working locally to address climate change.

Components of Successful Service-Learning Projects

Service learning is a teaching strategy that integrates meaningful community activity with instruction and reflection to enrich the learning experience, teach civic responsibility, and strengthen communities. Through service learning young people apply what they learn in the classroom to help address problems in their communities, regions, and the world. They gain from the practical applications of their studies, and they become active citizens contributing through the services they perform. Important components of service-learning projects include the following:

- **Ideally, students play a key role in designing and implementing the project**. The student voice is a key part of service-learning projects. Students should identify community needs and issues, help choose

ADRIAN DELGADO, FRIENDS OF THE NATIONAL FORESTS AND GRASSLANDS IN TEXAS

This activity allows students to apply their knowledge to plan and complete a service-learning project related to climate change and forests.

and plan the project, reflect on each stage of the project, evaluate it at the end, and celebrate its success. Teachers can facilitate the discussions about project ideas, available resources, project timeline, implementation strategies, and evaluation of results.

- **Encourage students to choose a project that will benefit the community and meet an identified need**. Service learning tackles complex problems in complex settings, not simplified (or hypothetical) issues in isolation. Students learn that they can affect their community and make meaningful change.
- **Teachers can integrate the project into the curriculum**. When service-learning projects are connected to curriculum, students experience a deeper understanding of the material. The results are immediate and meaningful; students are not simply trying to find the right answer. The project should engage students in active problem solving and encourage them to gain specialized knowledge, rather than generalized knowledge such as might come from a textbook. Service learning promotes social, emotional, and cognitive learning and development.
- **Relevant community partners are involved**. Community partners can include students from local universities or colleges, parents, community based organizations, teachers, school administrators, and service recipients. All partners should contribute to the planning and implementation of the project and benefit from it. Teachers can either contact these community partners directly or work with students to develop a list of relevant community partners to contact.
- **Students are given time to evaluate, reflect, and celebrate project achievements**. Teachers should give students time to reflect before, during, and after the project. Students should evaluate the progress they have made toward the learning and service goals of the project. Achievements should be celebrated to reinforce the good work students are doing.

This means that educators, students, and local partners must be involved in helping to select a project appropriate for your community—and one that all partners can embrace.

Project Ideas

Environmental action projects can take many forms, cost various amounts of money, and take different amounts of time to complete. For example, with relatively few funds, your students can establish an appropriate carbon-emission reduction plan for the school grounds or the local community. They could also develop forest and climate outreach activities for elementary or middle school students. For projects that require more funding, such as buying and planting trees, you can help students seek grants from the PLT Greenworks! program, the local school board, or an environmental organization or local business.

The following list provides a few ideas that may help get you get started on a brainstorming session with students.

- Explore student or community attitudes and knowledge about climate change, local forests, and climate change solutions. Based on the results, students could create educational materials and events (e.g., video, brochure, school festival, media event, or a presentation to community leaders) to increase knowledge, awareness, or encourage behavior change of other students, parents, or community members.

- Calculate the personal ***carbon footprint*** of students in one class, grade level, or the entire school and determine strategies for reducing carbon footprints by certain amounts. Students can organize competitions among classes or grades and track progress over time. There are many possibilities for energy saving projects from campaigns for turning off lights to changes in air conditioning and heating practices. Students may also be interested in raising funds to offset carbon ***emissions*** from various school activities by purchasing carbon credits through an organization that plants trees for carbon sequestration purposes. The following are useful personal carbon footprint calculators for students:
  - U.S. EPA, Carbon Footprint Calculator: http://epa.gov/climatechange/kids/calc/index.html
  - The Nature Conservancy, Carbon Footprint Calculator: http://www.nature.org/greenliving/carboncalculator/index.htm
- Create a plan for managing a nearby forest with a climate ***mitigation*** objective. This could involve measuring and monitoring tree growth, calculating carbon sequestration, assessing potential impacts from climate change, and recommending management actions. Students could then present the plan to the landowner, organization, or agency.
- Determine a public area that could be improved with more trees and work with community partners to create a plan and hold a tree-planting event.
- Learn about and assess ***forest health*** issues related to climate change in the area (e.g., ***wildfire*** risk, ***invasive species***, insects, diseases) and obtain permission and cooperation from the managing agency to plan a community work day to raise awareness and improve conditions at a specific forest or natural area.
- Explore the purchasing process for the school (or another organization) and determine a set of criteria that emphasizes carbon sequestration, substitution, and reductions. Present these criteria to the people who make purchasing decisions.

PLT Greenworks!

The PLT Greenworks! program provides grants to schools and youth organizations to engage students in service-learning projects. Applicants for this grant must

Environmental action projects can take many forms, cost various amounts of money, and take different amounts of time to complete.

Systems Thinking Connection

TEACHERS REPORT that one of the most important benefits of ***systems thinking*** is enabling their students to ask better questions. When designing their own environmental action project, students may be able to ask exceptionally good questions about how changes might affect the ***system***. You may want to have students consider the following systems-related questions as they develop their project:

- What are the key ***stocks*** in the system that you are trying to affect? One of the likely stocks targeted in these projects is atmospheric carbon. There are other important factors that can be considered stocks and can play a role in the success of the project, such as public knowledge of the need to address climate change, student enthusiasm for maintaining a long-term project, and administrative support from the school or local community.
- What are the cause-effect relationships that affect the system's behavior? What are the reinforcing and balancing feedback loops in the system? Capturing the power of the right ***reinforcing feedback loop*** may help your project achieve outcomes you never expected. What indirect effects might result from the project? Are there unintended effects or consequences that are potentially or likely to occur?
- What are the potential impacts of the project at different scales? Conducting a project will likely affect individual students (e.g., learning outcomes, skill building, self-confidence), the class (e.g., classroom management, enthusiasm), and the environment—which might be within the school or the community. How can students plan and carry out the project to attain the hoped-for impacts at each level?

have completed a PLT workshop, and the grant must be completed in one year. The project should involve service learning, exemplify student voice, involve at least one community partner, and secure 50 percent matched funds (in-kind resources are acceptable). Check out the PLT GreenWorks! webpage (http://www.plt.org/greenworks) for tips and ideas for your project and to see examples of past projects. Past projects include creating outdoor classrooms and nature areas, planting trees and hosting public events on forest conservation, and restoring habitat, among many other examples.

An important aspect of service-learning projects is to allow students to play a key role in designing and implementing the project.

PROJECT LEARNING TREE

Teaching This Content

Facilitating an action project can be a challenge. On the one hand you want students to embark on a project that they can complete successfully. On the other hand, the more you direct their project, the less powerful the learning experience for the students! As a result, teachers often adopt a style similar to inquiry teaching where they ask questions that prompt student observations and deliberation. You can make sure students assess their skills and resources and consider their likelihood of success. You can ask that they contact local resource people to obtain advice. In the end, you want students to feel that they made a difference, so both protecting and empowering your students may be important objectives. The Youth and Leader Guides to Give Forests a Hand provides step-by-step suggestions for conducting and facilitating action projects (http://edis.ifas.ufl.edu/fr117 and http://edis.ifas.ufl.edu/fr118).

Getting Ready

The Activity 14 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section5/activity14).

Review the documents and websites in the Resources section of this activity so you know where to go for questions and assistance along the way.

Before selecting and launching a project, help your students consider the scope of the project and possible limitations of what they can do. If you are considering a school-based project, you may wish to talk to your administrator and maintenance staff about the types of projects that would be welcomed. Make sure that students speak to appropriate advisors so that everyone shares an understanding of the potential project opportunities and limits or barriers to success.

Make copies of the student page.

Doing the Activity

1. Ask students to brainstorm and list as many ideas as possible that describe potential environmental action projects that their school or community could complete related to forests and climate change. What are the potential objectives for project ideas? How would the project benefit the community? What are the climate change implications of the project? If the school has a school forest, is there anything students can do to help manage the area? Are the suggested projects feasible? What barriers might exist?

2. As a class, select a few of the best ideas to investigate further. Help your students survey the proposed area, collect relevant data, and/or interview others about the project ideas. They should be seeking information and opinions on how the proposed environmental action ideas might be improved.

3. After the initial data collection, help students select the idea that has the most potential for success within the timeframe available and then create a plan for the project. They may wish to divide into teams based on interests in order to carry out specific components of the project.

4. Determine the ways in which this project can be connected to your curriculum and the learning objectives for students.

5. The Planning Your Project student page is available to help students finalize the objectives for the action plan and evaluate the resources, approval, or support required for carrying out these objectives. Decide whether you'd like students to complete this student page individually or in teams and pass out copies.

When students have finished a draft of the plan, they should evaluate it using the following questions:

- Is any additional information needed before we begin the project?
- What alternative actions could be taken to solve the problem?
- Is the action that we propose the best one? Why?
- What are the ecological, social, and economic impacts of this project?
- Do we have the skills, time, and materials needed for the project? If not, who can help?
- Who should review and approve the plan?

6. Using the evaluation, students can make adjustments to the plan.

7. Depending on the project, you may wish to have students present the plan to administrators, community leaders, partners, or other parties that will be involved. If so, have students use presentation software to make a final version of the plan and help them practice and present to this group.

8. Help students think about how they might demonstrate the value of their project. Can they take photographs before and after? Can they measure something that might change? If so, encourage them to record information before the project begins.

9. Help students carry out the project as planned.

10. Provide adequate time throughout for students to reflect on their experiences through journals, blogs, and small group discussions. By considering what they have done and the progress they are making, they are more likely to increase their capacity and skills to learn from their experience.

11. Systems Reflection: Ask students to describe the system that their project affects. How does their project play a role in changing the relationships between variables or creating a new connection? Did they observe any unintended impacts that they did not anticipate? Could they see any ripple effects of additional impacts?

12. Systems Reflection: When systems thinkers are trying to effect change, they often use the concept of leverage points. These are points in the system that allow people to maximize the benefits of their actions due to the structure of the system. For example, the best first step to achieving big results may be a very small project. The confidence and excitement resulting from that success will set the stage for the next step and may be contagious around your school or even in other nearby schools. Where are the leverage points in your school?
It may be helpful to enlist the support of the student council, or other teachers of the same grade, to help the message spread more quickly.

Providing adequate time for reflection allows students to evaluate their progress and assimilate what they have learned.

13. Decide with your students how they will share information about the project with the larger community and celebrate their success. For example, this can be done by presenting to other schools or community organizations, having a media day at the school, writing news releases, using social media, or creating a video. Implement these ideas to showcase project accomplishments and lessons learned. It may be hard to know when the project is over, so you may want to establish a milestone or indicator to allow students to experience a sense of accomplishment and closure. And that's when you can celebrate! An opportunity to reflect on the skills and perspectives they have gained can be a useful culmination of an action project. It also helps to have recognition from an administrator or the community to validate their efforts.

Modifications

Provide a set of possible action projects that meet the skills and abilities of your students.

Younger students may find it challenging to assess their abilities, compare competing plans, and select anything other than their first idea. You might limit their projects to the classroom or school site.

If you can take your students on a field trip to a public natural area, ask the manager if the class might assist in some activity. You might also ask the county forester or city arborist, for example, to suggest potential projects.

Enrichment

Have students write an environmental action project handbook for future students based on what they learned. What worked? What did not work? What did they wish they had known at the beginning? They can post their handbook on a website with photos of their activities. You can also share your reports, photos, or success stories on the module website—just use the "Contact Us" area and let us know that you have service-learning project information to share (https://sfcc.plt.org/contact/).

Additional Resources

Environmental Service Learning
Treepeople
www.treepeople.org/environmental- service-learning
This website provides information about seven key elements for quality service learning and provides project examples.

Give Forests a Hand, Leader and Youth Action Guides, Circular 1269 and 1270
Janice Easton, Martha Monroe, Alison Bowers, and Lizzie Peme; University of Florida; 2009
http://edis.ifas.ufl.edu/fr118 and http://edis.ifas.ufl.edu/fr117
This resource includes a youth action guide and a leader guide to help students identify potential projects, select an idea that matches their abilities, create a plan, conduct the project, and celebrate results. Reflection questions are built into the guide to encourage learning. Spanish versions are available.

GreenWorks!
Project Learning Tree
www.plt.org/greenworks
This webpage provides information on the PLT service-learning community action program, which provides grant opportunities annually.

National Service-Learning Clearinghouse
Corporation for National and Community Service
www.servicelearning.org
This comprehensive resource has answers to general questions about service learning and provides success stories. A subsection of this website focuses specifically on environmental issues.

Young Voices for the Planet, The Movies
Young Voices on Climate Change
www.youngvoicesonclimatechange.com/climate-change-videos.php
This series of short films presents replicable success stories of young people tackling climate change issues in their communities. Accompanying curriculum for each video is also available.

Planning Your Project (1 of 2)

NAME DATE

To plan your action project, try to answer as many of the following questions as possible.

Background Information and Problem Identification

1. What is the area or audience identified for the project?

2. What is the need for this project? How do you know this is a problem?

3. What existing data or information may be useful as you begin considering how to solve this problem?

Recommendations

4. What are some potential actions that could address the problem?

5. Which action(s) do you recommend? Why?

Planning Your Project (2 of 2)

Details of the Project

6. Who will be involved in this project? Who will do the work?

7. What community or school partners can help?

8. How much will it cost? Where will the money come from?

9. How does the project benefit the community or school?

Expected Results

10. What results do you hope the project achieves?

11. How will you know whether the project was successful?

GLOSSARY

Many of the definitions listed in this section were taken from other Project Learning Tree materials, specifically the *PreK-8 Environmental Education Activity Guide*, *Exploring Environmental Issues: Focus on Forests, Exploring Environmental Issues: Biodiversity,* and the *Energy & Society Activity Guide*. Other definitions come directly from three sources available on the Internet: the U.S. Forest Service's *Climate Change Glossary*; and two documents from the U.S. Environmental Protection Agency, *Glossary of Climate Change Terms* and *A Student's Guide to Global Climate Change*. Please see the reference list at the end of this glossary for the full citations for these and other sources consulted and cited.

Adaptation: Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change includes actions taken by humans to avoid, benefit from, or deal with actual or expected climate change impacts. Adaptation can take place in advance (by planning before an expected impact occurs) or in response to changes that are already occurring.

Afforestation: The planting of new forests on lands that historically have not had forests.

Albedo: The fraction of incoming solar radiation that is reflected from an object or surface (State Climate Office of North Carolina, n.d.).

Alleles: The alternative states of a particular gene (McCall, 2012).

Atmosphere: The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen and oxygen, together with a number of trace gases, such as argon, helium, carbon dioxide, and ozone. In addition the atmosphere contains water vapor, clouds, and aerosols.

ATP (Adenosine Triphosphate): A molecule used as an energy source in many biochemical reactions in living things (USFS, 2003).

Balancing feedback loop: A closed sequence of causes and events that tends to resist change in a complex system. Also known as a negative feedback loop.

Best management practices (BMPs): Acceptable and effective practices that can be implemented to prevent or reduce water pollution and promote soil conservation. Usually BMPs are applied as a system of practices rather than a single practice (NCFS, 2011; USFS, 2004).

Biodiversity: The variety and complexity of species present and interacting in an ecosystem and the relative abundance of each.

Biomass: The total weight of all living matter in a particular area at a given moment in time. Some kinds of biomass, such as wood and corn (after conversion to ethanol), can be burned to produce energy.

Carbon cycle: The movement of carbon (flux), in its various forms, from one place (pool) to another through various chemical, physical, geological, and biological processes.

Carbon dioxide (CO_2): A naturally occurring gas that is also a by-product of human activities, such as burning fossil fuels and biomass. Carbon dioxide is a greenhouse gas.

Carbon dioxide equivalent: Basic unit for measuring the global warming potential of emissions that is expressed in terms of the amount of carbon dioxide that would cause the same amount of warming. For example, over a period of 100 years, 1 pound of methane will trap as much heat as 25 pounds of carbon dioxide. Thus, 1 pound of methane is equal to 25 pounds of carbon dioxide equivalents (BBC, 2010).

Carbon flux: Process or rate by which carbon moves from one pool to another.

Carbon footprint: A measure of how much carbon dioxide a person, organization, or product produces—directly or indirectly—in a certain amount of time (usually a year).

Carbon pool: Any place where carbon can be found, such as plants, soils, the atmosphere, or fossil fuels. Carbon pools can also be called *stocks* or *reservoirs*.

Carbon savings: Reductions in atmospheric carbon dioxide that result from using products, such as wood, which sequester carbon, instead of products that cause more carbon to be put into the atmosphere, such as concrete.

Carbon sequestration: Process of capturing and storing atmospheric carbon dioxide into above- or below-ground carbon pools, such as plant biomass, through photosynthesis or into soils by plant decomposition.

Carbon sink: A carbon pool that absorbs and stores more carbon than it releases over some period of time, which helps to offset greenhouse gas emissions. Examples include the ocean, mature forests, and soil.

Carbon source: A carbon pool that releases more carbon than it absorbs over some period of time. Examples include the burning of fossil fuels, forest fires, and livestock.

Carbon storage: The amount of carbon that exists in a tree's leaves and stem at a particular point in time. This is the total amount of carbon that is captured from the atmosphere during photosynthesis as well as the amount of carbon sequestered by the tree.

Causal loop diagram: A tool used to visualize and analyze causal relationships in complex systems. Also referred to as a "systems diagram" in this module.

Chromosome: A rod-like body found in the cell nucleus that contains genes (McCall, 2012).

Climate change: Major changes in average temperature, precipitation, or wind patterns, among others, that occur over several decades or longer as a result of changes in Earth's atmosphere.

Climate: The long-term average weather conditions in a particular location or region at a particular time of the year. Climate is not the same as weather.

Clinometer: An instrument that uses trigonometry to determine the height of a tree.

Composition: The species that constitute a plant or forest ecosystem (SAF, 1998).

Conservation: The use of natural resources in a way that assures a continuing availability to future generations; the intelligent use of natural resources for long-term benefits.

Decomposition: The chemical and mechanical breakdown of matter into simpler parts by bacteria, fungi, and other organisms.

Deforestation: The removal of a forest stand where the land is put to a nonforest use (SAF, 1998).

Diameter at breast height (DBH): The diameter of a tree as measured at breast height. Standard DBH is measured at 1.4 meters (4.5 feet) above the ground.

Dry weight: The weight of the tree when it is dried in an oven and all water was taken out.

Ecosystem: A system of interacting living organisms together with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to the entire Earth.

El Niño-Southern Oscillation (ENSO): An atmosphere-ocean phenomenon that results from El Niño, a warm-water current that periodically flows along the coast of Ecuador and Peru, and the Southern Oscillation, a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific Oceans. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific and affects climate in many other parts of the world.

Emissions: In the climate change context, emissions refer to the release of greenhouse gases, precursors of greenhouse gases, and aerosols into the atmosphere over a specified area and period of time.

Evaporation: A physical change of state in which a liquid is transformed into a vapor or gas.

Exponential growth: An increase that begins slowly and then becomes increasingly more rapid over time.

Extension: A non-formal education program that provides scientific knowledge and expertise to the public, as part of the mission of land-grant universities.

Externality: An impact on a third party caused by a decision made by a producer or consumer. Externalities can be social or environmental and either positive or negative (Biz/ed, 2012).

Family: In the context of the genetic research of pine tree traits, a family consists of individuals that share one or both parents. (This is different from a botanical "family" which is a classification of related genera and species.)

Flow: A material or information that increases or decreases a stock at some rate over a period of time (Ponto & Linder, 2011).

Forest health: The ability of a forest ecosystem to remain productive, resilient, and stable over time and to withstand the effects of periodic natural or human-caused stresses such as climate changes, disease, drought, flood, insect attack, resource demands, and resource management practices.

Forest management: The practical application of biological, economic, and social sciences to the administration of a forest.

Forest product substitution: The practice (in the building of homes and other buildings, for example) of using wood instead of other products, such as concrete or steel.

Forester: A person professionally trained in and applying principles and practices for managing, using, and enjoying forests.

Fossil fuel: Coal, oil, natural gas, and other energy sources that formed by natural processes in the ground over millions of years from the remains of ancient plants and animals.

Genes: Small parts of DNA that carry the genetic code (McCall, 2012).

Genetic diversity: The genetic variation present in a population or species.

Genetic fitness: The reproductive success of a genotype, usually measured as the number of offspring produced by an individual that survive to reproductive age relative to the average for the population.

Genotype: The genetic makeup of an individual.

Global warming potential (GWP): A measure of how much heat a substance can trap in the atmosphere. GWP can be used to compare the effects of different greenhouse gases. For example, methane has a GWP of 25, which means over a period of 100 years, 1 pound of methane will trap 25 times more heat than 1 pound of carbon dioxide (which has a GWP of 1).

Global warming: An increase in the average surface temperature on Earth.

Grasslands: A vegetative community in which grasses are the dominant plants.

Green weight: An estimate of the weight of the tree when it is alive. This weight includes all parts of the tree and any water that is in the tree.

Greenhouse effect: The trapping of heat in Earth's atmosphere by gases, such as carbon dioxide, methane, nitrous oxide, and water vapor, that results in an increase in temperature at Earth's surface.

Greenhouse gases: Gases in Earth's lower atmosphere that trap heat and affect the average temperature on Earth. Examples are carbon dioxide, chlorofluorocarbons, ozone, methane, water vapor, and nitrous oxide.

Greenhouse gas emissions: The release of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, into the atmosphere.

Groundwater: Water that infiltrates through the soil and into clay and limestone layers and is stored in slowly creeping and slowly renewed underground reservoirs called "*aquifers*."

Habitat: An area that provides an animal or plant with adequate food, water, shelter, and living space in a suitable arrangement.

Harvest: To cut down trees for human use.

Heterozygous: An individual whose alleles for a particular trait are different (McCall, 2012).

Hydrocarbons: Organic compounds that occur in fossil fuels that contain only hydrogen and carbon.

Industrial private forest landowner: An ownership class of forestland that is administered by entities that are legally incorporated (Butler & Wear, 2011).

Invasive species: A type of plant, animal, or other organism, usually not native to the area it affects, which can spread quickly and can cause harm to the economy, the environment, or human health.

Life cycle assessment (LCA): A technique to assess the environmental aspects and potential impacts associated with all life cycle stages of a product, process, or service. This information can be used by scientists, policymakers, and citizens to make decisions about products to produce and/or purchase (U.S. Environmental Protection Agency, 2006).

Limestone: A type of sedimentary rock that is composed mostly of calcium carbonate and is often formed when ocean sediments, containing the shells of marine animals, are compressed and buried under the ocean floor. Limestone is a long-term carbon sink that can store carbon for hundreds of millions of years (Riebeek, 2011).

Long-lived wood product: Wood products—such as lumber used in housing—that store carbon for many years. The lifespan of lumber in housing is often estimated to be 80 years (Lippke et al., 2012).

Mitigation: A human intervention to reduce the human impact on the climate system. This may include actions and strategies to reduce sources of greenhouse gases or increase the amount of carbon dioxide being removed from the atmosphere.

Model: A quantitative tool that combines data from many variables and uses mathematical equations to approximate processes and systems over time. Climate models represent the interactions of the atmosphere, oceans, land surface, and ice; can range from relatively simple to quite comprehensive; and can be used to simulate climate and make climate predictions.

Naturally regenerated forest: A forest where trees primarily reproduce from seed, sprouts, or root suckers of trees on or that formerly occupied the land (Virginia Department of Forestry, 2014).

Negative externality: A cost (harmful impact) incurred by a third party due to a decision made by a producer or consumer (Biz/ed, 2012).

Non-industrial private forest landowner: An ownership class of forestland that is held by families (including trusts, estates and partnerships), individuals, or other unincorporated groupings of individuals, such as recreational clubs, or Native American lands (Butler & Wear, 2011).

Nonrenewable resource: A substance that once used cannot be replaced in this geological age. Examples are oil, gas, coal, copper, and gold.

Nontimber forest products: All forest products except timber. Examples are resins; oils, leaves and bark; fungi; plants that produce berries, fibers, or flowers for human use; and animals or animal products.

Ocean acidification: Increased concentrations of carbon dioxide in seawater that cause a measurable increase in acidity (i.e., a reduction in ocean pH). This reduces calcification rates of organisms such as corals, mollusks, algae, and crustaceans.

pH: A measure of the acidity or alkalinity of a material. The pH scale is 0 to 14; 7 represents a neutral state; 0, the most acidic; and 14, the most alkaline.

Phenotype: A characteristic of an animal, plant, or other organism that can be seen or measured. Examples are eye color, tree diameter, tree height, or even number of branches (McCall, 2012).

Photosynthesis: The process by which green plants produce oxygen and glucose, a carbon-based molecule, in the presence of carbon dioxide, sunlight, and water.

Plantation: A forest established by planting seeds or seedlings.

Positive externality: A beneficial impact on a third party due to a decision made by a producer or consumer (Biz/ed, 2012).

Precipitation: Water from the atmosphere that falls to the ground. Examples include rain, mist, snow, sleet, and hail.

Prescribed fire: Any planned fire ignited in a natural area by trained professionals under appropriate weather and safety conditions to meet specific objectives, including the reduction of wildfire risk and the maintenance or restoration of fire-dependent ecosystems.

Product life cycle: The many steps that go into creating, using, and disposing of a product. Life cycle includes the acquisition of raw materials, bulk material processing, engineered materials production, manufacture and assembly, use, retirement, and disposal of residuals produced in each stage (U.S. Environmental Protection Agency, 2006).

Productivity: The rate of generation of biomass in an ecosystem.

Progeny: An offspring of a plant or animal.

Projection: Description of how future climate is expected to respond to various scenarios of the factors that might affect climate change, such as population growth, greenhouse gas emissions, and land development patterns.

Recycle: The practice of reprocessing waste materials (such as glass, plastic, paper, and aluminum) so that they can be used to manufacture new products.

Reinforcing feedback loop: A closed sequence of causes and events that tends to amplify change in a complex system. Also known as a positive feedback loop.

Renewable resource: A naturally occurring raw material or form of energy that has the capacity to replenish itself through ecological cycles and sound management practices. The sun, wind, falling water, and trees are examples of renewable resources.

Resilience: The ability of an ecosystem or species to remain whole and functioning as it copes with stress (The Conservation Fund, 2013).

Respiration: The process whereby living organisms extract energy from carbon-containing molecules, releasing carbon dioxide and consuming oxygen.

Scientific uncertainty: The range of values within which the true value is likely to fall (Understanding Science, 2013).

Sea level rise: An increase in the mean level of the ocean.

Sediment: Solid mineral and organic material that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice.

Service learning: A teaching strategy that integrates meaningful community activity with instruction and reflection to enrich the learning experience, teach civic responsibility, and strengthen communities.

Sequestration: See carbon sequestration.

Short-lived wood products: Wood products, such as paper, that store carbon for a relatively shorter time frame when compared to long-lived wood products such as housing lumber. Carbon is returned to the atmosphere when the product decays or decomposes, which is often estimated to take 45 years (Lippke et al., 2012).

Silviculture: The art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands. Silviculture entails the manipulation of forest and woodland vegetation in stands and on landscapes to meet the diverse needs and values of landowners and society on a sustainable basis.

Soil Carbon: Carbon stored within soil. Carbon which is transferred to the soil from dead plant and animal material.

Solar radiation: Energy emitted by the sun.

Species: A population of organisms composed of related individuals that resemble one another and freely breed among themselves.

Stock: A quantity that accumulates over time. A stock increases by a flow in (inflow / input) and decreases by a flow out (outflow / output) (Ponto & Linder, 2011).

Structure: The physical and temporal distribution of plants in a forest (SAF, 1998).

Sustainability: Creation and maintenance of conditions under which humans and nature can exist in productive harmony, thus fulfilling social, economic, and other requirements of present and future generations (EPA, n.d.).

System: A set of components interacting with each other and with the environment.

Systems thinking: A set of critical-thinking skills that help students understand complex phenomena.

Thin: The removal of some trees in a managed forest in order to improve the growth and health of the remaining trees.

Timber: Wood, other than fuelwood, potentially usable for lumber (SAF, 1998).

Topography: The natural and manmade features and relief of Earth's surface (State Climate Office of North Carolina, n.d.).

Transpiration: The process by which water moves from the soil through plants, which is driven by the evaporation of water from leaves.

Understory: The layer of trees and plants beneath the forest canopy.

Vegetation: Plants that cover a given area (e.g., trees, shrubs, herbs, grasses, and vines).

Weather: Atmospheric conditions at any given time or place, measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather changes from hour-to-hour, day-to-day, and season-to-season.

Wildfire: Any nonstructural fire on wildlands other than one intentionally set for management purposes.

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