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Unit Overview

Grade Level – adaptable 8th – 12th

TEACHERS – Are you hearing about greenhouse gases and global warming everywhere you turn? Carbon seems to be in the news everyday. Your students are likely hearing the same things you are. The following lesson plans will explain the terms that we hear in the media and provide a fundamental understanding of the topics.

The attached lessons were developed into a unit of study that will provide students with a basic understanding of the Carbon Cycle, Carbon Sequestration, the Greenhouse Effect, Global Warming and more specifically the interaction of trees and forests in all of these topics. The various sections consist of:

Vocabulary for learning about the Greenhouse Effect and Carbon Sequestration

- Science-based definitions
- Vocabulary lists specific to each exercise
- Crossword puzzle activity assesses vocabulary knowledge

Lessons that explain and explore the Carbon Cycle and its relationship with Forests

- Background information on the Global Carbon Cycle (terrestrial, oceanic, and atmospheric)
- Focus on the Carbon Cycle in Forests
- Discussion questions (and possible answers) included
- Classroom activity
- Two carbon cycle graphics; one developed based on the Department of Energy’s global carbon cycle and one developed by The Forest Foundation to focus a forest’s role in the carbon cycle

Experiment and background materials on the Greenhouse Effect and the Scientific Method

- Background information provides students with an understanding of how the Greenhouse Effect works and its importance
- Teaches and reinforces the Scientific Method
- Directions for experiment that illustrates the Greenhouse Effect and applies the Scientific Method
- Based on graphics and information from Project Learn by the University Corporation for Atmospheric Research

Game – Carbon Fingerprints

- Students will explore their personal impact on carbon emissions through a simple board game in which they accumulate or lose points based on real life scenarios

Math exercise – How Much Carbon Would a Woodchuck Chuck?

- Students will be given a set of data and formulas and will then be asked to complete various carbon calculations including storage, offsets, and emissions involving a forest stand, a catastrophic wildfire, and our daily activities

Life Cycle Assessment of Building Materials

- Explores current thinking in research regarding environmental impact of various products through Life Cycle Assessment
- Students design a research project using the Life Cycle Assessment approach to examine the environmental impacts of different building materials
## California State Science Content Standards Addressed in:

### Forests and the Carbon Cycle Curriculum Unit

<table>
<thead>
<tr>
<th>Grade</th>
<th>Standard Set</th>
<th>Standard Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Chemistry 6a, 6b</td>
<td>Carbon has a central role in the chemistry of living things. Living organisms are made of molecules consisting largely of carbon, hydrogen, oxygen, phosphorus, and sulfur.</td>
</tr>
<tr>
<td>9-12</td>
<td>Chemistry 10a, 10b</td>
<td>Bonding characteristics of carbon allow the formation of many different molecules.</td>
</tr>
<tr>
<td></td>
<td>Life Science - Biology 1f</td>
<td>Energy from the sun is captured by chloroplasts in the process of photosynthesis and is stored through the synthesis of sugars and starch from carbon dioxide, water and nutrients.</td>
</tr>
<tr>
<td></td>
<td>Life Science - Ecology 6b, 6d</td>
<td>Analyze changes in ecosystems resulting from changes in climate, human activity, etc. Know how water, carbon, and nitrogen cycle in an ecosystem.</td>
</tr>
<tr>
<td></td>
<td>Earth Science - Energy in Earth System 4b, 4c, 4d</td>
<td>Incoming solar radiation is reflected, absorbed, or used in photosynthesis. Know that different atmospheric gases absorb Earth’s thermal radiation and the significance of the greenhouse effect. Know the differing greenhouse conditions on Earth, Mars, and Venus; the origins of those conditions; and the climatic consequences of each.</td>
</tr>
<tr>
<td></td>
<td>Earth Science – Biogeochemical Cycles 7a, 7b</td>
<td>Know the global carbon cycle: the different physical and chemical forms of carbon in the atmosphere, oceans, biomass, fossil fuels, and the movement of carbon among these reservoirs.</td>
</tr>
<tr>
<td></td>
<td>Investigation and Experimentation</td>
<td>Scientific progress is made by asking meaningful questions and conducting careful investigations. Students should develop their own questions and perform investigations.</td>
</tr>
</tbody>
</table>
Forests and the Carbon Cycle

**California Career Technical Education Model Standards Addressed:**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Standard Set</th>
<th>Standard Description</th>
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</thead>
<tbody>
<tr>
<td>7-12</td>
<td>Math 10.0, 13.0</td>
<td>Solve multistep problems using addition, subtraction, multiplication and division.</td>
</tr>
<tr>
<td></td>
<td>Science 1.2</td>
<td>Application of investigation and experimentation.</td>
</tr>
<tr>
<td></td>
<td>Forestry/Natural Resources E1.1, E1.2, E1.5, E10.0, E10.1, E10.4</td>
<td>Understand biogeochemical cycles. Understand the difference between renewable and nonrenewable energy sources. Analyze the way human activities influence energy cycles and natural resource management. Understand forest management practices. Understand how social, political, and economic factors can affect the use of forests. Analyze harvest and renewability (e.g. re-seeding and thinning) systems and identify the impact of each on the land.</td>
</tr>
</tbody>
</table>

**Education and the Environment Initiative Principals Addressed:**

<table>
<thead>
<tr>
<th>Principal</th>
<th>Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>People Depend on Natural Systems (1a,1b,1c)</td>
<td>Goods produced by natural systems are essential to human life, economies, and cultures. Quality, quantity and reliability of ecosystem goods and services are directly affected by the health of those systems.</td>
</tr>
<tr>
<td>People Influence Natural Systems (2a,2b,2c)</td>
<td>Growth of human populations and methods used to manage natural resources influence the composition, biological diversity, and viability of natural systems.</td>
</tr>
<tr>
<td>Natural Systems Change in Ways that People Benefit from and can Influence (3a,3b,3c)</td>
<td>Natural systems proceed through cycles and processes that are required for their functioning. Human practices can alter the cycles.</td>
</tr>
<tr>
<td>There are no Permanent or Impermeable Boundaries that Prevent Matter from Flowing between Systems (4a,4b,4c)</td>
<td>Byproducts of human activity are not readily prevented from entering natural systems and may be beneficial, neutral, or detrimental in their effect.</td>
</tr>
<tr>
<td>Decisions Affecting Resources and Natural Systems are Complex and Involve Many Factors (5a,5b)</td>
<td>Know the spectrum of what is considered in making decisions about resources and natural systems and how those factors influence decisions.</td>
</tr>
</tbody>
</table>
Forests and the Carbon Cycle

**Carbon Cycle Vocabulary**

**Atmosphere**
The gaseous envelope surrounding the Earth.

**Biosphere**
The portion of the Earth comprising the lower atmosphere, the seas and land surfaces in which living organisms exist, together with all of the Earth’s living organisms (plants and animals).

**Biomass**
The term biomass has two definitions: 1) The total mass of living matter within a given unit of environmental area or 2) Plant material, vegetation, or agricultural waste used as a fuel or energy source.

**Carbon Cycle**
Movement of carbon, in its many forms (solid, liquid, and gas), between the biosphere, atmosphere, hydrosphere, and geosphere.

**Carbon Sequestration**
The removal and capture of available atmospheric carbon in plants, soils, oceans, or atmosphere. Trees in the forests, as well as forest products, are primary carbon sequestration mechanisms. Approximately 50% of wood consists of carbon. The place where the carbon is sequestered is often referred to as a carbon sink.

**Decomposition**
The breakdown of organic material into smaller molecules which are then recycled or used again by another organism. This is nature’s way of recycling. During the process carbon dioxide is released into the atmosphere.

**Emission**
The act of releasing or putting a substance into circulation making it available for chemical reaction. Often the word emission is a term used to describe pollution such as the gases given off by an automobile or a large forest fire; however it can also be used to describe gases that are given off by a tree or a human and released into the air. Contrast with Sequestration.

**Fossil fuels**
Fuels such as oil, natural gas, and coal. These combustible materials are found in the Earth’s crust and are the remains of prehistoric organisms. Burning fossil fuels typically results in a release of high levels of carbon into the atmosphere. Fossil fuels are a nonrenewable resource.

**Geosphere**
The solid part of the Earth.

**Gigaton**
One gigaton is equal to 1,000,000,000 metric tons (one billion metric tons). One metric ton = 1,000 kilograms = 2,205 pounds.

**Global Warming**
The theory that Earth’s surface temperature is rising as a result of the increased concentrations of various gases in the atmosphere called greenhouse gases.

**Greenhouse Effect**
The effect of various gases within the Earth’s atmosphere reflecting radiant energy back to the Earth’s surface similar to the effect which occurs in a greenhouse. Greenhouse gases, such as CO$_2$ (carbon dioxide), methane, and ozone, insulate and warm the Earth’s surface. Without the Greenhouse Effect life on Earth, as we know it, would not be possible and there would be no liquid water on the Earth. The greenhouse effect may be enhanced by increased levels of greenhouse gases in the atmosphere thus causing a greater warming of the Earth’s surface temperatures (Global Warming).

**Hydrosphere**
The Earth’s supply of water.

**Nonrenewable resource**
Resource used for making products or generating energy that take an extremely long time to regenerate (thousands or millions of years). Examples: oil, natural gas, coal.
**Photosynthesis**
The process whereby plants make the carbohydrates glucose, sucrose, and starch from sunlight, carbon dioxide, and water. During this process oxygen and water are released as byproducts. The carbon from the carbon dioxide is made into carbohydrates which are either used or stored. The carbohydrates that are used are converted to energy through the process of respiration; carbon dioxide and water are formed as byproducts. See Respiration. The carbon that is stored in the plant is said to be sequestered. See Carbon Sequestration.

**Phenomenon (plural phenomena)**
An observable fact or event.

**Qualitative**
Defined in terms of qualities or characteristics (For example, describing a friend one might say he has brown hair, blue eyes, and dark skin. Brown hair, blue eyes, and dark skin are all qualities or characteristics that are described.)

**Quantitative**
Expressed in terms of quantity, in other words, measurable. (For example, describing a friend one might say he is 5 feet 9 inches tall, weighs 170 pounds, and can run a mile in 8 minutes. His height, weight, and how fast he can run are all features that can be measured, or in other words are quantified.)

**Renewable resource**
Resource used for making products or for generating power that can be replenished or regenerated within a relatively short amount of time (within a human lifetime or less). Examples: trees, corn, sugar cane, sunshine, and wind.

**Respiration**
The process whereby plants and animals convert carbohydrates, water, and oxygen into energy, carbon dioxide and water are released as byproducts of this process. Both photosynthesis and respiration occur in plants. The difference between the carbon uptake through photosynthesis and carbon release through respiration is called net carbon uptake and is the amount of carbon that is sequestered. See Photosynthesis.

**Sequestration**
The act of forming a stable compound with so it is not available for chemical reaction. Contrast with Emission. See also Carbon Sequestration definition above.

**Sink and Source**
Within the carbon cycle a sink is any location where carbon is stored. A source is any location in the carbon cycle where carbon is released or made available for chemical reaction. Some examples of carbon sinks are forests, soil, and the ocean. A sink may be temporary. Carbon sinks can turn into carbon sources; for example, fossil fuels are sinks while they are buried in the Earth and wood is a sink. When the fossil fuels or wood are burned, carbon is released into the atmosphere and it is now called a carbon source.
Forests and the Carbon Cycle

Objective:
- To understand that carbon cycles from one form to another and the role that forests play in this process
- To understand where and how carbon is stored
- To understand what humans can do to increase carbon storage and reduce carbon emissions

Materials and Resources:
- Overhead projector
- Overhead slide of the Simplified Global Carbon Cycle
- Overhead slide of Forests and the Carbon Cycle
- Overhead slide of the Simplified Global Carbon Cycle with numbers

Procedure:
Use the following guide to teach the aspects of the carbon cycle, including the roles that humans and forests play in the cycle.

Vocabulary:
Atmosphere: The gaseous envelope surrounding the Earth.

Biomass: The term biomass has two definitions: 1) The total mass of living matter within a given unit of environmental area or 2) Plant material, vegetation, or agricultural waste used as a fuel or energy source.

Biosphere: The portion of the Earth comprising the lower atmosphere, the seas and land surfaces in which living organisms exist, together with all of the Earth’s living organisms (plants and animals).

Carbon Cycle: Movement of carbon, in its many forms (solid, liquid, and gas), between the biosphere, atmosphere, hydrosphere, and geosphere.

Carbon Sequestration: The removal and capture of available atmospheric carbon in plants, soils, oceans, or atmosphere. Trees in the forests, as well as forest products, are primary carbon sequestration mechanisms. Approximately 50% of wood consists of carbon. The place where the carbon is sequestered is often referred to as a carbon sink.

Decomposition: The breakdown of organic material into smaller molecules which are then recirculated or used again by another organism. This is nature’s way of recycling. During the process carbon dioxide is released into the atmosphere and some carbon is also transferred to the soil.

Emission: The act of releasing or putting a substance into circulation making it available for chemical reaction. Often the term emission is used to describe pollution such as the gases given off by an automobile or a large forest fire; however it can also be used to describe gases that are given off by a tree or a human and released into the air. Contrast with Sequestration.

Fossil fuels: Fuels such as oil, natural gas, and coal. These combustible materials are found in the Earth’s crust and are the remains of prehistoric organisms. Burning fossil fuels typically results in a release of high levels of carbon into the atmosphere. Fossil fuels are a nonrenewable resource.

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**Sequestration:** The act of forming a stable compound so it is not available for chemical reaction. Contrast with Emission. See also Carbon Sequestration definition above.

**Sink and Source:** Within the carbon cycle a **sink** is any location where carbon is stored. A **source** is any location in the carbon cycle where carbon is released or made available for chemical reaction. Some examples of carbon sinks are forests, soil, and the ocean. A sink may be temporary. Carbon sinks can turn into carbon sources; for example, fossil fuels are sinks while they are buried in the Earth and wood is a sink. When fossil fuels or wood are burned, carbon is released into the atmosphere and it is now called a carbon source.
Carbon is in most things around us; people, plants, trees, soil, oceans, and even the air we breathe. There is only a certain amount of carbon in, on, and around the Earth. The total amount of carbon stays the same, it just changes from one form to another. This is called a cycle.

The Carbon Cycle is the movement of carbon, in its many forms, between the biosphere (all of the Earth’s living organisms), atmosphere (the gaseous envelope surrounding the Earth), hydrosphere (the Earth’s supply of water), and geosphere (the solid part of the Earth).

Translated this means:

The Carbon Cycle is the movement of carbon, in its many forms, between 1) all living plants and animals, 2) the gas surrounding the Earth, 3) water, and 4) soil and rocks.

Put the slide of the Simplified Carbon Cycle on the overhead.

One of the first reactions might be, “Wow, that’s complicated.”

Breaking the cycle down into the separate pieces will show it is actually easy to understand. Point out to the students that there are really only a few main pieces to the carbon cycle;

1. The Atmosphere
2. Ocean exchange
3. Fossil fuels emissions
4. Terrestrial exchange

Atmosphere
[Start with the Atmosphere in the upper left of the diagram]. Carbon in the atmosphere is mostly in a form that students have heard about: CO₂ (carbon dioxide). Carbon dioxide is one of the greenhouse gases. Although we may think of the atmosphere as the area where exchange is primarily occurring, there is also a lot of carbon storage in the atmosphere. This is represented by the square box shown near the word Atmosphere. Remind the students that a place where carbon is stored is called a sink. Carbon storage is also called carbon sequestration. As well as this storage, much of the exchange of carbon occurs in the atmosphere. The atmosphere not only stores carbon but it also exchanges carbon back and forth between the ocean and the land.

There are three main ways for the carbon to enter or be removed from the atmosphere. These are through 1) ocean exchange, 2) fossil fuel emissions, and 3) terrestrial exchange.

Ocean exchange
[Now go to the right side midsection of the diagram].

Ocean exchange is the cycling back and forth of the carbon between the ocean water, ocean sediments, and the atmosphere. The ocean is also a large carbon sink and stores quite a bit of carbon especially in the deep ocean (see the square boxes in the ocean). The ocean stores carbon but it also exchanges carbon back and forth with the atmosphere at the ocean surface. Show the arrow going into the ocean where carbon is taken up from the atmosphere and the arrow going out of the ocean where carbon is released into the atmosphere.

Fossil fuel emissions
[Move to the center of the diagram]

Fossil fuel emissions refer to the carbon released into the atmosphere as a result of burning fossil fuels. This is shown by the circle shapes above the label Fossil Fuels. Some examples of fossil fuels are gas, oil, and coal. Fossil fuels were made from the decomposition of prehistoric organisms that were once living a long time ago and were exposed to the right conditions for a very long time (thousands and thousands, or even millions, of years). Fossil fuels are nonrenewable resources because they take so long to replenish.

The other activities included with the fossil fuels category are the generation of cement (which takes quite a bit of energy to make) and land use changes. Land use changes refers to land that once grew trees but was cleared for other activities such as growing crops, grazing animals, or development and is called deforestation because trees will not be replanted in the cleared areas. This is opposed to forest management in California where sustainable forest practices keep the land growing trees and storing carbon. Although both trees and plants sequester – or store – carbon, trees store far more carbon than plants such as grass.
The fossil fuels category is the only category in which carbon just goes one way in the cycle. Carbon moves only from storage to emissions in this process. (In the case of land use changes it could actually be a decrease in carbon sequestration rather than an increase in emissions but the end result is greater carbon levels in the atmosphere).

**Terrestrial exchange**

Terrestrial exchange—Terrestrial exchange refers to the land so the terrestrial exchange portion of the cycle refers to all of the exchanges that occur in association with the land. But terrestrial is not just the land itself; it is also those plants and animals living on the land. The exchange of carbon to and from terrestrial sources happens in many ways. Terrestrial exchange is mainly shown in this diagram by uptake or sequestration into plant biomass and soil (shown by the square boxes), and carbon releases from decomposition and respiration.

**Forests and the Carbon Cycle**

Now use the “The Carbon Cycle: Forestry Never Looked So Cool” overhead in order to focus on the role of forests in carbon cycling.

In all managed forests of California laws protect wildlife habitat, watersheds and require that trees are replanted in harvested areas. The diagram begins with a seedling being planted in the place of a harvested tree.

The center of the diagram shows carbon being stored in wood products. When carbon is stored in trees, wood products, and plants it is unavailable for chemical reaction. This is called sequestration. Ask the students to look around the classroom. What are some ways that carbon is stored in the form of wood in your classroom? (Some examples might be desks, chairs, pencils, paper, books, window frames, walls, picture frames, and doors)

The lower, middle section of the diagram illustrates the forest growth phase. During photosynthesis trees and plants absorb carbon and use it to make up the roots, wood, and leaves. Trees also release a small amount of carbon dioxide through the process of cellular respiration. Some of this carbon stored through photosynthesis is lost either when the leaves drop, or when the plant dies. At this point the carbon is transferred from the plant to the soil.

Another way that forests release carbon to the atmosphere is through forest fires. Low intensity forest fires can be an important part of forest ecology. The relationship between ecosystems and wildfire has developed over time in such a way that many species of plants and other processes depend on this natural disturbance to regenerate and maintain a healthy ecosystem. However, if a forest is not properly managed, small fires can turn into very large wildland fires (also called catastrophic fires) that harm the ecosystem and release a lot of carbon into the atmosphere. Unhealthy trees in the forest can be a fire hazard and also often sequester, or store, carbon at a lower rate. When trees are growing too densely in the forest they grow at a slower rate and therefore store less carbon per tree. These types of overcrowded forests can also create a fire hazard because if a fire starts it can spread more easily. Foresters manage the forest with properly spaced trees which enhances healthy tree growth and decreases the risk of catastrophic fire.

Energy can be generated in many different ways. When energy is produced from wood waste this is called renewable energy because the source can be renewed fairly quickly — by growing trees. Actually, since the energy is produced from wood waste this is recycling because the wood waste would have otherwise been thrown away and probably end up in landfill. This is a way to create a benefit from a waste product. Energy generated by this method is called Biomass Energy and is carbon neutral (which means that the carbon dioxide returned to the atmosphere on burning woody
Forests and the Carbon Cycle

biomass equals the amount of carbon dioxide taken up by the plant to produce the wood). [Now go to the very bottom center of the diagram]. Another way of generating energy is to use fossil fuels. Remember that fossil fuels are nonrenewable resources because they take so long to create. The fossil fuels (gas, oil, coal) that we are using now were made by decaying materials over thousands of years. Using fossil fuels releases a lot of carbon into the atmosphere.

The concepts in The Carbon Cycle: Forestry Never Looked So Cool graphic are well summarized in the following excerpt by Patrick Moore, Ph.D. in the Winter 2006 edition of California Forests.

Trees are the most powerful concentrators of carbon on Earth. Through photosynthesis, they absorb CO$_2$ from the atmosphere and store it in their wood, which is nearly 50 percent carbon by weight. The relationship between trees and greenhouse gases is simple enough on the surface. Trees grow by taking carbon dioxide from the atmosphere and, through photosynthesis, converting it into sugars. The sugars are then used as energy and material to build the cellulose and lignin that are the main constituents of wood. When a tree rots or burns the carbon contained in the wood is released back to the atmosphere. Active forest management, such as thinning, removing dead trees, and clearing debris from the forest floor is very effective in reducing the number and intensity of forest fires. And the wood that is removed can be put to good use for lumber, paper and energy.

The impact of forests on the global carbon cycle can be boiled down to these key points:

- On the negative side, the most important factor influencing the carbon cycle is deforestation which results in a permanent loss of forest cover and a large release of CO$_2$ into the atmosphere. Deforestation – which occurs primarily in tropical countries where forests are permanently cleared and converted to agriculture and urban settlement – is responsible for about 20 percent of global CO$_2$ emissions.

- On the positive side, planting fast-growing trees is the best way to absorb CO$_2$ from the atmosphere. Many countries with temperate forest have seen an increase in carbon stored in trees in recent years. This includes New Zealand, the United States, Sweden and Canada. Plus, using wood sustainably reduces the need for non-renewable fossil fuels and materials such as steel and concrete – the very causes of CO$_2$ emissions in the first place.

The good news is that forests in the United States are net carbon sinks, since annual growth exceeds annual harvest. We are currently experiencing an increase in forested land as forests are being re-established on land previously used for agriculture. Catastrophic wildfires are uncommon in managed forests, whereas millions of acres of unmanaged forests burn every year due to excessive build-up of dead trees and woody debris.

Every wood substitute, including steel, plastic and cement, requires far more energy to produce than lumber. More energy usually translates into more greenhouse gases in the form of fossil fuel consumption or cement production.

One of the best ways to address climate change is to use more wood, not less. Wood is simply the most abundant, biodegradable and renewable material on the planet.
Pulling it all together

Now that the students know the pieces of the Carbon Cycle have a class discussion.
Using the two graphics, have the students identify at least 3 carbon sinks and at least 3 carbon sources.

<table>
<thead>
<tr>
<th>Carbon Sinks:</th>
<th>Carbon Sources:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>Decomposition</td>
</tr>
<tr>
<td>Plant Biomass</td>
<td>Respiration</td>
</tr>
<tr>
<td>Soil</td>
<td>Burning Fossil Fuels</td>
</tr>
<tr>
<td>Rock</td>
<td>Wildland Fires</td>
</tr>
<tr>
<td>Fossil Pool</td>
<td>Ocean Exchange</td>
</tr>
<tr>
<td>(including fossil fuels before extraction)</td>
<td></td>
</tr>
<tr>
<td>Surface Ocean</td>
<td></td>
</tr>
<tr>
<td>Deep Ocean</td>
<td></td>
</tr>
<tr>
<td>Reactive Sediments</td>
<td></td>
</tr>
<tr>
<td>Wood Products</td>
<td></td>
</tr>
</tbody>
</table>

Are there some things that were both sinks and sources but at different times? Talk about a few of those. The ocean takes up carbon but it also releases carbon. As you saw, the Atmosphere is a carbon sink but it also has carbon available to react in both Terrestrial and Ocean Exchange. Even trees which are very good at carbon sequestration can be a carbon source when decomposing, burning in wildland fires, or carrying out cellular respiration. The process of decomposition both stores some carbon in the soil and releases some carbon to the Atmosphere. Fossil fuels are a sink while buried in the ground but a source when they are extracted and burned.

Like most natural cycles, there are aspects to the Carbon Cycle that humans cannot directly influence (such as ocean exchange).

How can human activities influence the Carbon Cycle?
Examples of some possible answers are:

- Plant trees to help store more carbon
- Use wood products that store carbon from sustainably managed forests
- Using public transportation, riding a bike or walking when possible rather than driving a car
- Manage forests to grow healthy trees because healthy trees store more carbon
- Recycling materials that can be recycled
- Manage forests to prevent large forest fires that release a lot of carbon into the atmosphere
- Use renewable energy sources and support development of new renewable energy sources such as biomass energy
- Decrease use of fossil fuels which release high levels of carbon into the atmosphere
- Reduce the amount of trash that the family produces
- Conserving electricity and heating fuels
  - Use energy efficient appliances and turn them off when not in use
  - Use energy efficient bulbs
  - Set house temperatures lower in the winter and higher in the summer
- Use renewable resources which generally release less carbon than nonrenewable resources
- Reuse building materials which will keep carbon stored longer
Teacher’s Explanation for the Numbers on the Slide Titled Global Carbon Cycle with Numbers

Now that the students understand the pieces of the carbon cycle you can put up the slide titled the Simplified Carbon Cycle with numbers. The following numbers come from the Simplified Global Carbon cycle graphic generated by the Department of Energy Office of Science (http://genomicsgtl.energy.gov/benefits/climate.shtml).

All of the numbers on the cycle represent gigatons. (A gigaton is one billion metric tons, see vocabulary). The numbers with the squares show the total amount of carbon stored in that form. For example, the number 800 for atmosphere shows that there are 800 gigatons of carbon stored in the atmosphere. Now look at the amount of carbon stored in rock. That shows that there are 70,000,000 gigatons of carbon stored as rock in and on the Earth. You get the idea of storage numbers now. The numbers with the triangles and circles show the amount of carbon that is exchanged each year. The triangles show the carbon that is taken up and stored (also called sequestration) by various sinks and the circles show the carbon released from the various sources. Taking into account the entire carbon cycle across the Earth, all of the uptakes and releases result in a net annual release of about 3-4 gigatons of carbon to the atmosphere every year. It may seem surprising but -- Yes, even though some of the numbers for carbon storage are quite large the net exchanges annually are relatively small. These annual numbers are the numbers typically discussed in the news. And the focus in the news is typically carbon released by the fossil fuel emissions. As you have explored with your students above, there are many ways for humans to influence the annual carbon exchanges, both positively and negatively.

Ocean Exchanges
Considering the exchanges back and forth with the ocean, this process results in the storage or sequestration of about 2 gigatons of carbon. That’s after we look at both what is taken up by the ocean and what is released from the ocean. The ocean takes up and stores (or sequesters) about 90 gigatons of carbon each year but it also releases about 88 gigatons of carbon in the same time period. So if we subtract the 88 gigatons produced from the 90 gigatons stored we see that the end result is that the ocean sequesters about 2 gigatons of carbon each year.

Fossil Fuels
Activities in the fossil fuels category produce about 6 gigatons of carbon emissions each year.

Terrestrial Exchanges
Terrestrial exchanges result in the storage or sequestration of about 0-1 gigatons of carbon each year. Through the process of terrestrial exchanges about 120 gigatons of carbon are sequestered each year but there are also releases of about 119-120 gigatons of carbon in the same time period. So if we subtract the 119-120 gigatons produced from the 120 gigatons stored we see that the end result is that by terrestrial exchanges sequester about 0-1 gigatons of carbon each year.

So, when we look at the numbers (in gigatons) for the Global Carbon Cycle they look like this:

<table>
<thead>
<tr>
<th>Ocean</th>
<th>Terrestrial</th>
<th>Fossil Fuels</th>
<th>Total Carbon Introduced to Atmosphere Each Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-2)</td>
<td>(0 to -1)</td>
<td>(+6)</td>
<td>3 to 4 gigatons</td>
</tr>
</tbody>
</table>

(negative numbers represent net carbon sequestration, while positive numbers represent net carbon emissions)

- Ask students to generate a list of ways that forests could increase the terrestrial uptake of carbon.
On the Board Exercise
A fun exercise to do with the whole class is to calculate pounds of carbon in one of the sinks. (This could be particularly dramatic if you write the number across the board.)

Here is the formula:
Y (the sink amount from the graphic) in gigatons x 1,000,000,000 x 2,205 = Z pounds (the sink amount in pounds)

Background numbers for formula:
1 gigaton = 1,000,000,000 metric tons (one billion metric tons)
1 metric ton = 2,205 pounds (rounded up from 2,204.6)

Examples:
How many pounds of carbon are stored in Plant Biomass on the Earth?
The graphic shows 500 gigatons stored in Plant Biomass, so it would be:
500 gigatons x 1,000,000,000 metric tons x 2,205 pounds = 1,102,500,000,000,000 pounds of carbon stored in Plant Biomass on the Earth (this number is called one quadrillion, 102 trillion, 500 billion.)

Of course this can also be written in the form called scientific notation which would make the number:
1.1025 x 10^{15}

The long form makes the number more dramatic for this exercise. However, these may be some very good examples for the usefulness of scientific notation.

Are we ready to jump into the really, really big one? Yes? OK, here we go….
How many pounds of carbon are stored in Rock on the Earth?
The graphic shows 70,000,000 gigatons (70 million gigatons) stored in Rock, so it would be:
70,000,000 gigatons x 1,000,000,000 metric tons x 2,205 pounds = 154,350,000,000,000,000,000 (154 quintillion 350 quadrillion pounds of carbon stored in Rock on the Earth.

(This formula is stated as: 70 million gigatons times one billion metric tons times 2,205 pounds equals 154 quintillion 350 quadrillion pounds of carbon stored in Rock on the Earth.) In scientific notation this formula would be written: (7.0 x 10^7)(1.0 x 10^9)(2.205 x 10^3) = 1.5435 x 10^{20}

This is obviously a HUGE number. Here is a way to help the students visualize this number:

One quintillion pennies, if laid out flat like a carpet, would cover the surface of the earth - twice. So, if we consider the number 154 quintillion above, that would be a carpet of pennies covering the entire Earth to a depth of over two and a half feet. How tall are you? How high does two and a half feet come on you? To your shoulders? To your belly? To your hips? To your knees?
Forests and the Carbon Cycle

Carbon Cycle Overhead Graphic

Photosynthesis

Simplified Global Carbon Cycle

Ocean

Terrestrial Exchange

Fossil Fuels

Respiration

Microbial decomposition

Rock

Soil

Deep ocean

Surface ocean

Atmosphere

Fossil pool

Soil carbon

Rock

Ocean water and sediments

Plant biomass

Reactive sediments

Microbial

Soil carbon

Fossil pool

Deep ocean

Soil

Atmosphere

Simplified Global Carbon Cycle

N = stored carbon

L = carbon released

S = carbon uptake
Forests and the Carbon Cycle

Simplified Global Carbon Cycle with Numbers

- Atmosphere: 800 Gt
- Fossil Fuels: 120 Gt
- Plant Biomass: 500 Gt
- Soil Carbon: 2,500 Gt
- Reactive Sediments: 3,000 Gt
- Ocean Water and Sediments: 1,000 Gt
- Rock Pool: 38,000 Gt
- Deep Ocean: 3,000 Gt
- Soil: 2,200 Gt
- Fossil pool: 70,000 Gt

N = stored carbon (gigatons)
S = carbon uptake (gigatons)
L = carbon released (gigatons)

Carbon Cycle Overhead Graphic

Photosynthesis
Terrestrial Exchange
Fossil Fuels
Ocean Exchange
**Carbon Cycle**

**ACROSS**

2. The breakdown of organic material into smaller molecules which are then recirculated or used again by another organism

8. The solid part of the Earth

10. Resources used for making products or generating energy that take an extremely long time to regenerate (thousands or millions of years)

16. Combustible materials found in the Earth's crust which are the remains of prehistoric organisms (examples are oil, natural gas, and coal)

17. This term means both: 1) The total mass of living matter within a given unit of environmental area or 2) Plant material, vegetation, or agricultural waste used as a fuel or energy source

18. The process whereby plants and animals convert carbohydrate, water, and oxygen into energy, carbon dioxide and water are released as by products of this process

19. The effect of various gases within the Earth's atmosphere reflecting radiant energy back to the Earth's surface similar to the effect which occurs in a greenhouse

**DOWN**

1. Expressed in terms of quantity, in other words, measurable

3. The removal and capture of available atmospheric carbon in plants, soils, oceans, or atmosphere.

4. The Earth's supply of water

5. The theory that the Earth's surface temperature is rising as a result of the increased concentrations of various gases in the atmosphere called greenhouse gases

6. An observable fact or event

7. The process whereby plants make food (carbohydrates, such as the sugar glucose) from sunlight, carbon dioxide, and water

8. 1,000,000,000 metric tons (one billion metric tons)

9. Resources used for making products or for generating power that can be replenished or regenerated within a relatively short amount of time (within a human lifetime or less)

11. All of the Earth's living organisms (plants and animals)

12. The gaseous envelope surrounding the Earth

13. Movement of carbon, in its many forms (solid, liquid, and gas) between the biosphere, atmosphere, hydrosphere and geosphere.

14. The act of releasing or putting a substance into circulation making it available for chemical reaction

15. Defined in terms of qualities or characteristics
Carbon Cycle

Decomposition

Geosphere

Oceans

Nonrenewable Resources

Tertiary

Hat

Secondary

INHOSPITALITY

BIOLOGICAL

DECOMPOSITION

A

R

P

H

O

T

G

A

S

T

Y

O

T

Q

E

A

N

E

V

T

S

A

I

M

N

E

H

A

T

B

I

O

C

A

E

Q

U

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S

L

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A

E

R

P

G

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M

B

I

S

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E

E

F

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S

I

E

N

C

I

Y

O

B

M

A

S

N

S

I

T

I

V

E

C

L

S

Greenhouse Effect
The Earth’s Greenhouse Effect and The Scientific Method

Objective
To understand and be able to apply the Scientific Method. To understand the Greenhouse Effect as it relates to the Earth.

Materials and Resources
This experiment requires:
- Two identical thermometers
- One jar or other clear container that will fit over the thermometer
- One watch or clock
- One data recording worksheet (included with directions)
- A sunlamp or access to a sunny area.

Procedures
This lesson will introduce the idea of the Scientific Method as well as the Earth’s Greenhouse Effect. After reviewing these materials the students will then perform an experiment to observe a simulation of the Greenhouse Effect and apply the Scientific Method.

Vocabulary
Global warming: The theory that Earth’s surface temperature is rising as a result of the increased concentrations of various gases in the atmosphere called greenhouse gases.

Greenhouse Effect: The effect of various gases within the Earth’s atmosphere reflecting radiant energy back to the Earth’s surface similar to the effect which occurs in a greenhouse. Greenhouse gases, such as CO2 (carbon dioxide), methane, and ozone, insulate and warm the Earth’s surface. Without the Greenhouse Effect life on Earth, as we know it, would not be possible and there would be no liquid water on the Earth. The greenhouse effect may be enhanced by increased levels of greenhouse gases in the atmosphere thus causing a greater warming of the Earth’s surface temperatures (Global Warming).

Phenomenon (plural phenomena): An observable fact or event.

Qualitative: Defined in terms of qualities or characteristics. (For example, describing a friend one might say he has brown hair, blue eyes, and dark skin. Brown hair, blue eyes, and dark skin are all qualities or characteristics that are described.)

Quantitative: Expressed in terms of quantity (i.e. measurable). (For example, describing a friend one might say he is 5 feet 9 inches tall, weighs 170 pounds, and can run a mile in 8 minutes. His height, weight, and how fast he can run are all features that can be measured, or in other words are quantified.)
The Scientific Method
Science. What do you think of when you hear the word Science? Some people might think of a scientist in a neat white lab coat with sensible glasses. Some might think about a cartoon of a mad scientist with wild hair surrounded by colorful, bubbling beakers pouring smoking mixtures between test tubes. Really, science is a pretty basic idea. Science is the systematic study of anything that can be examined, tested, and verified using the scientific method. Science is applied in many different ways by many different kinds of scientists. But they all use the same method in testing their ideas; the scientific method.

There are some facts about the world that we take to be true. A few examples are the existence of gravity, the Earth revolves around the sun, and the boiling point of water is 212° F. We know these things as facts because somewhere a scientist had an idea and tested it. Scientists test ideas or principles by applying the scientific method. Careful application of the scientific method guides research, or the testing of ideas, in order to ensure that one is not lead to a false conclusion.

So what is the Scientific Method?

There are five main steps to the Scientific Method:

1. Observation and description of a phenomenon or group of phenomena.
   This step can also include asking a question.

2. Formulation of a hypothesis to explain the phenomena.
   What is an explanation for the phenomenon?

3. Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.
   Now we take the hypothesis a step further and refine the thought based on available information to develop the experimental approach.

4. Performance of experimental tests of the predictions by several independent experimenters and properly performed experiments.
   (Performance of tests by several experimenters is called replication and means that the experiment must be able to be repeated and achieve the same results in order to be determined reliable. This is where data collection is involved.)

5. The final step is to assess the hypothesis.
   Based on the data collected, is the hypothesis accepted or rejected? This is one of the most difficult aspects of the process – to make an assessment in an unbiased way. Unbiased means to leave aside our preconceived ideas that we bring to the experience.
Forests and the Carbon Cycle

Here is an example of the application of the Scientific Method on the boiling point of water.

1. Observation and description of a phenomenon: Water boils
2. Formulation of a hypothesis to explain the phenomenon: When enough heat is applied to water it transforms from liquid to gas.
3. Use of the hypothesis to predict quantitatively the results of new observations: The specific point of heating when water changes from liquid to gas is at the temperature 212° F
4. Performance of experimental tests of the predictions by several independent experimenters and properly performed experiments: Water was repeatedly heated and the temperature was recorded at which water boiled, or turned from the liquid to the gaseous state. Data are collected.
5. The hypothesis is now considered in light of the data. The hypothesis was that water will transform from liquid to gas at 212° F. The data collected confirmed this hypothesis. However, if the data showed that water transforms at 220° F then the researcher would have to go back to the first step and start over again. That is why there are question marks in the arrow from step 5 to step 1. The researcher may have to reconsider the question or consider a new question in light of the data or results of the experiment.

Background for The Earth’s Greenhouse Effect Experiment

Some scientists explain the Earth’s atmosphere by using the Goldilocks Principle. The Goldilocks Principle can be summed up as neatly as “Venus is too hot, Mars is too cold, and Earth is just right.” The Earth has an average surface temperature comfortably between the boiling point and freezing point of water making it suitable for our sort of life. This cannot be explained by simply suggesting that our planet orbits at just the right distance from the sun to absorb just the right amount of solar radiation. Our moderate temperatures are also the result of having just the right kind of atmosphere. A Venus-type atmosphere would produce extremely hot conditions on our planet. A Mars atmosphere would leave us shivering in a sub-zero deep freeze.

Instead, parts of our atmosphere act as an insulating blanket of just the right thickness and composition, trapping sufficient solar energy to keep the global average temperature in a pleasant range. The Martian blanket is too thin, and the Venusian blanket is way too thick! The ‘blanket’ here is a collection of atmospheric gases called ‘greenhouse gases’ based on the idea that the gases also ‘trap’ heat like the glass walls of a greenhouse do.

<table>
<thead>
<tr>
<th></th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface temperature</td>
<td>450°C</td>
<td>13°C</td>
<td>-80°F</td>
</tr>
</tbody>
</table>

Greenhouse Gases

These gases, mainly water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), all act as effective global insulators. After heat energy enters the Earth’s atmosphere, some is absorbed by the planet while some is reflected back to space. Of that energy reflected back to space, some is redirected by the greenhouse gases and is reflected back to the Earth again. (Infrared radiation is heat energy of particular wavelengths.) This is very similar to the idea that the glass of the greenhouse lets the light through and keeps warm air contained.
Solar Radiation

The sun radiates vast quantities of energy into space, across a wide spectrum of wavelengths.

Most of the radiant energy from the sun is concentrated in the visible and near-visible parts of the spectrum. The narrow band of visible light, between 400 and 700 nanometers (nm), represents 43% of the total radiant energy emitted. Wavelengths shorter than the visible account for 7 to 8% of the total, but are extremely important because of their high energy per photon. The shorter the wavelength of light, the more energy it contains. Thus, ultraviolet light, also called UV, is very energetic (capable of breaking apart stable biological molecules and causing sunburn and skin cancers). The remaining 49 - 50% of the radiant energy is spread over the wavelengths longer than those of visible light. These lie in the near infrared range from 700 to 1000 nm; the thermal infrared, between 5000 and 20,000 nanometers; and the far infrared regions. Various components of Earth’s atmosphere absorb ultraviolet and infrared solar radiation before it penetrates to the surface, but the atmosphere is quite transparent to visible light.

Absorbed by land, oceans, and vegetation at the surface, the visible light is either transformed into heat and re-radiates in the form of invisible infrared radiation, or the energy is used to create vegetative matter through photosynthesis. If that was all there was to the story, then during the day Earth would heat up, but at night, all the accumulated energy would radiate back into space and the planet’s surface temperature would fall far below zero very rapidly. The reason this doesn’t happen is that earth’s atmosphere contains molecules that absorb the heat and re-radiate the heat in all directions. These molecules are called ‘greenhouse gases’ because they serve to hold heat in like the glass walls of a greenhouse. Greenhouse gases are responsible for the fact that the Earth enjoys temperatures suitable for our active and complex biosphere.

Atmospheric scientists (scientists who study the gaseous envelope surrounding the Earth) first used the term ‘greenhouse effect’ in the early 1800s. At that time, it was used to describe the naturally occurring functions of trace gases in the atmosphere and did not have any negative connotations. It was not until the mid-1950s that the term greenhouse effect was coupled with concern about changes in the global climate. And in recent decades, we often hear about the greenhouse effect in somewhat negative terms. The negative concerns are related to the possible impacts of an enhanced greenhouse effect. The enhanced greenhouse effect is sometimes called Global Warming. Global Warming refers to the gradual increase of the Earth’s average surface temperature due to a build-up of greenhouse gases in the atmosphere. It is important to remember that without the greenhouse effect life on Earth, as we know it, would not be possible.

The term Greenhouse Effect comes from the idea that greenhouse gases produce an effect similar to the glass walls of a greenhouse. Both greenhouse gases around the Earth and the glass walls of a greenhouse allow solar radiation to enter a space and hold the heat generated by the solar radiation.

The source of this material is Project Learn at http://www.ucar.edu/learn from the University Corporation for Atmospheric Research (UCAR).
The Greenhouse Effect in a Jar Experiment

In this experiment you will use a jar to simulate the effect of Greenhouse gases around the Earth and apply the Scientific Method.

Formulate a Hypothesis: Read over the experiment. Record what you think will happen during this experiment. Remember, this must be expressed quantitatively.

Develop an Experiment:

What you need:  
2 Small Identical Thermometers
1 clock or watch
1 data recording worksheet (below)
Sunlamp or access to a sunny area
1 Jar or other clear container that will fit over one thermometer

How to do it:  
1. Place the two thermometers a few inches apart and equal distance from the sunlamp or in the direct sun
2. Wait 3 minutes and record the temperature readings of both thermometers.
3. Place a jar over one of the thermometers. Every minute, for ten minutes, record the readings of both thermometers.

Gather Evidence (Data): Record your data in the table below.

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature of Thermometer #1</th>
<th>Temperature of Thermometer #2 covered by jar</th>
</tr>
</thead>
<tbody>
<tr>
<td>First observation with both thermometers outside jar (after 3 min.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Place the jar over Thermometer #2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Plot the data that you collected on the graph below in the form of a bar graph. When you label the axes remember to include the units. Use different colors to represent each thermometer.

On the bar graph Thermometer #1 is represented by _______ and Thermometer #2 by _______.

Label for Y axes _________________________________

Label for X axes _________________________________

Explain what happened:

Why did this happen?

What does the glass jar represent in this experiment?

Did you accept or reject the hypothesis you developed?

How could a reduction of greenhouse gases be simulated in this experiment?

Compare class results.
Can your results be determined reliable? Why or why not?
Forests and the Carbon Cycle

The Earth’s Greenhouse Effect Experiment

Explanation for Teachers:

The air around the exposed thermometer is constantly changing. As the air warms and rises it is replaced by cooler air. Because the air in the jar can’t circulate to the rest of the room, this air stays in the jar and gets warmer and warmer. A similar trapping of heat energy happens in the Earth's atmosphere. Sunlight passes through the atmosphere and warms the Earth’s surface. The heat radiating from the surface is trapped by greenhouse gases and is reflected back to Earth. This warming due to heat-trapping gases is called the “Greenhouse Effect”. The processes work slightly differently but result in the same effect. The thermometer in the jar illustrates the Earth’s Greenhouse Effect. The Greenhouse Effect produces conditions that make the Earth habitable.

Remember that the negative concerns regarding the Earth’s warming are related to the possible impacts of an enhanced, human-caused greenhouse effect. The enhanced greenhouse effect is sometimes called Global Warming. Global Warming refers to the gradual increase of the Earth’s average surface temperature due to a build-up of greenhouse gases in the atmosphere mainly from burning fossil fuels. It is important to remember that without the greenhouse effect life on Earth, as we know it, would not be possible.

Be sure to have the students write their Hypothesis before they start collecting their data.

Example Hypothesis:

After being under the jar for 10 minutes the temperature of thermometer #2 will be higher than the temperature of thermometer #1 not under the jar.

Possible Answers to the State your Conclusions Questions:

Explain what happened:

The air around thermometer #2 under the jar became hotter than the air around thermometer #1 not under the jar.

Why did this happen?

The air around the thermometer #2 in the jar was heated and not allowed to circulate with cooler air in the room. The jar held in the radiant energy (heat) as the Greenhouse gases in the Earth’s atmosphere hold radiant energy (heat) close to the Earth. The air around thermometer #1 was able to circulate with the relatively cooler air in the room and therefore did not increase in temperature.

What does the glass jar represent in this experiment?

The jar represents Greenhouse gases in the Earth’s atmosphere.

Did you accept or reject the Hypothesis you developed?

The student would accept the hypothesis if it is support by the data collected and reject it if not supported by the data collected.
**Carbon Fingerprints**

**A game for analyzing our impact on the carbon cycle**
Most of us have heard about calculating our carbon footprint. A carbon footprint calculates the amount of carbon which is released into the atmosphere as a result of a year’s worth of activities. The calculation is based on those activities that are the larger carbon producers, for example, airplane flights, how many miles you drive a car in a year or how much energy you use in a year. It is the everyday decisions you make which contribute to the total annual amounts. In this game we’ll look at these everyday decisions. Since these everyday activities are smaller actions we thought we’d call them your carbon “fingerprints.” Play the game and see how you do with a random point accumulation. Then go back and look at all of the spaces and think about how each of your daily decisions adds up at the end of the year if you make all your choices one way or the other. In other words, what happens if every single decision you make is to increase carbon storage and reduce your carbon emission versus not having that focus?

**Items needed to play game:**
One die, one small stone for each player to use as a token, one piece of paper for each player to keep a tally of points.

**Directions:**
Players roll a die and move long the path of the board. With each move players record their points on their tally card and add or subtract the indicated number of points. Part of the game involves talking about the actions and consequences of each square.
Forests and the Carbon Cycle

Carbon Fingerprints Game

Start

- Choose a career in forestry so you can help manage healthy forests, which store carbon, reduce catastrophic fires, and provide renewable, recyclable wood products (+3)
- The research project you chose is to learn about biomass energy (+2)
- Suggest that a diseased tree be replaced with a young seedling that will sequester carbon at a higher rate (+2)
- Volunteer to help with a research project at your school to survey trees that are sequestering carbon at high rates (+2)
- Throw water bottle into garbage rather than recycling (-2)
- Decide to play video games rather than going for a hike in the woods (-1)
- Turn down the opportunity to help plant new trees in your community (-3)
- Participate in a woods tour and ask a forester about forest land management practices (+2)
- Leave lights on in your bedroom while you are at school (-2)
- Take the elevator instead of the stairs (-2)
- Ask for paper grocery bags since they are made from a renewable resource and can be recycled (+1)
- Give a class presentation on the carbon cycle and explain ways to decrease carbon emissions and increase carbon storage (+2)
- Reuse wood from an old building to build a skateboard ramp (+3)
- The research project you chose is to learn about biomass energy (+2)
- Suggest that a diseased tree be replaced with a young seedling that will sequester carbon at a higher rate (+2)
- Volunteer to help with a research project at your school to survey trees that are sequestering carbon at high rates (+2)
- Throw water bottle into garbage rather than recycling (-2)
- Decide to play video games rather than going for a hike in the woods (-1)
- Turn down the opportunity to help plant new trees in your community (-3)
- Participate in a woods tour and ask a forester about forest land management practices (+2)
- Leave lights on in your bedroom while you are at school (-2)
- Take the elevator instead of the stairs (-2)
- Ask for paper grocery bags since they are made from a renewable resource and can be recycled (+1)
- Give a class presentation on the carbon cycle and explain ways to decrease carbon emissions and increase carbon storage (+2)
- Reuse wood from an old building to build a skateboard ramp (+3)

E2
To Play Carbon fingerprints – each player requires a small stone to use as a token, and a tally card. Players roll a die and move along the woodland path. With each move, players record their points on their tally card. Discuss the actions and consequences of each square. The player with the most points wins!
How Much Carbon Would a Woodchuck Chuck?

Objective:
To learn about relative amounts of carbon storage in forests and wood products and the relationship to emissions from catastrophic forest fires.

Materials and Resources:
Basic Calculator.

Procedures:
This lesson will walk the students through a series of formulas to calculate carbon storage and carbon emissions associated with a forest stand using multiplication, addition and subtraction.

Vocabulary for this exercise:

Biomass:
Living matter – in this case, the living matter in trees (trunks, branches, and foliage).

CO\textsubscript{2}e (e for equivalent):
Is the equivalent of the greenhouse gas global warming potential of carbon dioxide, methane, and nitrous oxide added together and converted to the warming potential of carbon dioxide.

DBH:
Tree diameter at breast height or 4.5 feet above the ground. This is a standard measurement used to categorize the size of trees.

Thinning:
A harvesting action designed to reduce competition among trees within a stand and improve growing conditions for the remaining trees.

Figure 1. Example of a dense Sierra Nevada ponderosa pine – white fir forest.
**Introduction**

We’ve all heard the age-old question “How much wood would a woodchuck chuck if a woodchuck could chuck wood?” While this woodchuck is chucking its wood, let’s find out how much carbon is involved.

To answer the question “How much carbon would a woodchuck chuck?” you need to know how much carbon trees store. Trees store different amounts of carbon based on species, diameter, and age.

A group of trees in a forest is called a “stand.” Our example stand is typical of dense forests in the Sierra Nevada. Table 1 describes the stand. A dense stand is a stand that has many trees per acre (as opposed to a sparse stand which has few trees per acre).

Notice that young fir trees, that are tolerant of shade, dominate the understory, or lower level, of this forest. Older pine trees that need full sunlight dominate the overstory, or upper level. This means over time fir trees will take over the forest as the pine trees die. That is, unless the forest is thinned to let in more sunlight. Thinning would give the pine trees an opportunity to regenerate and remain in the forest.

Another important factor regarding carbon storage in a forest stand is the age of the stand, although we won’t directly deal with this in our calculations. Younger trees grow at a faster rate and therefore store carbon at a higher rate than older trees. Healthy trees store carbon at a higher rate than diseased and dying trees. As you will see later in the exercise, large out-of-control wildland fires can contribute huge amounts of carbon to the atmosphere.

Managing a forest can address all of these issues.

For example, over many hundreds of years in America’s history there have been fires in the forests both natural and human caused. These fires were typically small and acted to reduce the build up of woody materials called fuel for large wildland fires. These small fires no longer occur on a regular basis because of a change in human practices. As a result, many unmanaged forests have built up large stores of woody fuel. This is one of the reasons that large wildland fires can rage out of control when they start. Forest management can help prevent these very large wildland fires by reducing the amount of woody fuel that remains in the forests. Forest management also helps promote the growth of healthy trees which are less prone to burning than dead or dying trees. These healthier trees also store carbon at a faster rate than overcrowded, stressed trees.

**Project**

We want to calculate how much carbon is stored in a forest and the solid wood products that are made from harvested trees. In addition, we want to learn how much CO$_2$ (a greenhouse gas) is released into the atmosphere if the stand of trees was subject to a catastrophic wildfire.

**How Much Carbon is Stored in a Forest Stand?**

*This exercise uses Table 1 on the Answer Sheet.*

The size of the tree is tracked by a measurement called the dbh which is the diameter at breast height or 4.5 feet above the ground. Use the following formulas to calculate the total amount of carbon stored in the forest stand. **Our example forest stand is 1000 acres.** The amount of carbon in trees is calculated based on the biomass of the tree. Carbon is half of the biomass of the tree.

Table 1 Column A on the Answer Sheet shows the amount of carbon stored in the ponderosa pine and white fir trees in an acre. Sum the amount of carbon stored in the trees of one acre (column C) and then multiply by the total number of acres to arrive at the total carbon storage in the stand.

*Enter answer in box A on Answer Sheet.*

Did you notice the different number of trees in each size class of the stand? This is called the size class distribution for a stand.
How Much Carbon is Stored in Wood Products Made from Trees Harvested from the Forest Stand?

Use the formulas below to calculate how much of this stored carbon would remain stored in solid wood products after harvesting this stand.

The total amount of carbon stored in the stand includes all tree sizes and the carbon in the roots. Trees in the 2 inch dbh size are not harvested for making solid wood products and roots are not used in the generation of wood products.

We will need to subtract out the carbon stored in the components that won’t be harvested. The carbon stored in both the pine and fir 2 inch or smaller trees of this stand is 1,565 tons. The carbon stored in the roots of this stand is 13,715 tons. About 43% of the remaining stand is harvested.

Harvested carbon (tons) = 
0.43 * [Total carbon stored in stand – (2 inch dbh or smaller trees + carbon stored in roots)]

Enter answer in Box B on Answer Sheet.

The amount of wood processed is typically about 85% of that harvested (which means roughly 15% is bark). Of that, about 62% is available to be turned into wood products.

Total wood product carbon (tons) = 
0.85 * 0.62 * harvested carbon

Enter answer in Box C on Answer Sheet.

Now that you have calculated the amount of carbon that would be stored in the wood products generated from this stand, let’s consider what happens next. After harvest the stand is replanted. Within two years after the stand is harvested there are new trees regrowing and storing carbon. That means that carbon is stored in the wood products made from the harvested trees and new carbon is also being stored by the young trees that were replanted and are now growing on the site. Identify some of the wood products you use everyday that store carbon.

How Much Carbon is Released to the Atmosphere During a Catastrophic Wildfire?

If this forest stand burns in a catastrophic wildfire, there is a large amount of carbon that would be converted from storage in the trees to greenhouse gas emissions to the atmosphere. These emissions occur immediately from combustion and over about a century from the decay of the remaining dead biomass.

In this Exercise we will determine how much carbon in the form of CO₂ releases to the atmosphere from combustion and decay if there is a catastrophic wildfire that kills 100% of this stand. (Remember, this analysis doesn’t include methane (CH₄) and nitrous oxide (N₂O) emissions which are more potent greenhouse gases than CO₂ but they release in much smaller amounts than CO₂.) In order to calculate the fire emissions we need to have some more specific numbers on how the above ground biomass is stored.

The first step is to break up the above ground biomass into stems, branches, and foliage. Even so, this analysis doesn’t include litter, duff, understory vegetation, down dead wood, or standing dead trees, all of which are important in calculating total emissions from wildfire.

This exercise uses Table 2 on the Answer Sheet.

Assuming 100% mortality, the amount of carbon in the biomass consumed by the fire is the percent consumption times the carbon in each fuel component (stems, branches, foliage, and roots).

Carbon burned during biomass combustion (tons) = [Fuel Consumption] * [Total Stand Carbon]

Enter the results in Table 2, Column C and total.

The amount of CO₂ released by combustion in the fire is the emission factor times the carbon in the biomass consumed in each fuel component (stems, branches, foliage, and roots).

The emission of CO₂ from each fuel component is based on an emission factor published by the California Air Resources Board. These were converted to ratios shown in Table 2, Column D. These emission factors represent the amount of gas released per ton (or other unit of weight) of biomass consumed by wildfire.
You probably noticed that each ton of fuel emits more than one ton of CO$_2$. The reason is simple. CO$_2$ is a molecule composed of carbon and oxygen, each of which has a different weight or mass.

The molecular weight of CO$_2$ is 44 (C is 12, O is 16, and O$_2$ is 32, which totals 44). Therefore, since 44 (the molecular weight of CO$_2$) divided by 12 (the molecular weight of carbon) is 3.67, that means for each unit of carbon consumed by fire 3.67 units of CO$_2$ is emitted. This is expressed here as tons/ton.

Similarly, for each ton of carbon consumed, approximately 3.67 times the carbon consumed is emitted as CO$_2$. This is the theoretical emission factor for wood fuel in tons/ton of fuel consumed by combustion.

The California Air Resources Board made precise measurements based on fuel components that differ slightly from the theoretical, as shown in Table 2.

$$\text{CO}_2 \text{ emissions from combustion (tons)} = [\text{carbon consumed during combustion}] \times [\text{emission factor for CO}_2]$$

Enter the results in Table 2, Column E and total.

There is a large amount of unburned biomass left to decay after a wildfire in various fuel components (stems, branches, foliage, and roots).

$$\text{Carbon in unburned dead biomass in the stand (tons)} = [\text{total stand carbon}] - [\text{carbon consumed during combustion}]$$

Enter the results in Table 2, Column F and total.

The amount of CO$_2$ released by decay after a wildfire is often much greater than emissions from the fire itself because the unburned biomass is much larger than the biomass consumed in the fire.

Unburned dead biomass takes about 100 years to decay. Even so, the release of CO$_2$ from decay is still a result of the wildfire and contributes to climate change.

$$\text{CO}_2 \text{ released by decay in the stand (tons)} = [(3.67) \times (unburned carbon in the stand)]$$

Enter the results in Table 2, Column G and total.

The total CO$_2$ emissions from a wildfire is the sum of emissions from combustion and decay, which represents the total impact of the wildfire on climate change.

$$\text{Total CO}_2 \text{ released by wildfire in the stand (tons)} = [\text{CO}_2 \text{ emissions from combustion}] + [\text{CO}_2 \text{ emissions from decay}]$$

Enter the results in Table 2, Column H and total.

Were there any surprising results in this exercise? Did you expect that decomposition would contribute so much carbon to the atmosphere? What are the main differences between the carbon that is contributed to the atmosphere through combustion and the carbon contributed through decomposition? What is the Number of Cars that Would Produce Emissions Equal to the Catastrophic Wildfire?

For our last calculation we’ll head to your driveway. You already figured out how much carbon is stored in this forest stand, stored in solid wood products, and released into the atmosphere as CO$_2$ (a greenhouse gas) by a catastrophic wildfire. You also know that cars produce carbon emissions. How do the two relate?

The last calculation is to figure out how many passenger cars on the road for a year equate to CO$_2$, released into the atmosphere when this forest burns. Again, we all have cars of different sizes and efficiencies.

For this exercise, we will use an average passenger car with a fuel efficiency of 22.1 miles per gallon traveling an average of 12,000 miles per year. According to the Department of Transportation, this average passenger car emits 5.03 metric tons of CO$_2$e per year. A metric ton is equal to 1.1023 English short tons, which is what we are using in this analysis. Therefore, tailpipe emissions from an average passenger car are 5.54 tons CO$_2$e per year.

What is CO$_2$e? It is CO$_2$ equivalent. It is the equivalent of the greenhouse gas global warming potential of carbon dioxide, methane, and nitrous oxide added together and converted to the warming potential of carbon dioxide.

Compute the equivalent in passenger cars added to the road for one year from CO$_2$ emissions caused by combustion and decay from this catastrophic wildfire. Looking at this a different way, this is the same number of passenger cars that would have to be locked in a garage for one year to make up for the greenhouse gas emissions from this wildfire. It is important to
recognize that 1,000 acres is a very small wildfire. Some California wildfires in this type of forest burn as much as 150,000 acres.

**Passenger car equivalents** = \([\text{total stand CO}_2 \text{ emissions total}] / [5.54]\)

Enter answer in Box D on Answer Sheet.

This is a conservative approximation. The number of passenger car equivalents would be slightly higher if we had calculated the emissions of methane and nitrous oxide from the wildfire and included their more potent global warming potential. In other words, calculating CO\(_2\)e emissions from the catastrophic wildfire instead of just CO\(_2\) would have increased the equivalent number of passenger cars.

Compute the equivalent in passenger cars added to the road for one year per acre burned from CO\(_2\) emissions caused by combustion and decay from this catastrophic wildfire.

**Passenger car equivalents from combustion and decay per acre burned** = \([\text{total stand CO}_2 \text{ emissions total}] / (5.54)] / [1,000 \text{ acres}]\)

Enter answer in Box E on Answer Sheet.

Now that you know how to make this conversion it would be an interesting exercise to find out how many acres of forested land (public and private) there are in California versus how many personal vehicles there are on the road in the State.

The following web sites may be useful in researching these questions:

The Forest Foundation
www.calforestfoundation.org
click on teacher or student tab and go to Ask a Forestry Question

California Department of Transportation
http://www.dot.ca.gov/

California Environmental Protection Agency
http://www.calepa.ca.gov/

The California Forest Products Commission
www.caforests.org
click on ownerships

United States Forest Service
http://www.fs.fed.us/

**Summary**

You have now calculated how much carbon is stored in things around you everyday such as trees and wood products, how much carbon is released into the atmosphere in an example catastrophic wildfire, and how many average passenger cars produce the same amount of carbon as the catastrophic wildfire. If the stand were managed to promote the health and growth of the trees in the stand how do you think this would affect:

- The amount of carbon stored in the stand and the wood products produced from the stand harvest?
- The likelihood of the stand burning as extensively, and why?
- The amount of carbon released into the atmosphere if the stand caught on fire?

This set of math exercises was developed in conjunction with Thomas M. Bonnicksen, Ph.D.
Table 1

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<td>Emission Factor for CO₂</td>
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Box A

Total carbon stored in the trees of the stand (tons) =

Box B

Harvested carbon (tons) =

Box C

Total wood product carbon (tons) =

Box D

Passenger car equivalents (# of cars) =

Box E

Passenger car equivalents from combustion and decay per acre burned (# of cars) =
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### Box A

- Total carbon stored in the trees of the stand (tons) = 70,760

### Box B

- Harvested carbon (tons) = 23,856.4

### Box C

- Total Carbon in Wood Product (tons) = 12,572.3

### Box D

- Passenger car equivalents (# of cars) = 45,742.35

### Box E

- Passenger car equivalents from combustion and decay per acre burned (# of cars) = 45.74
Life Cycle Assessment of Building Materials

Objective:
To introduce and explore the concept of Life Cycle Assessment.

Materials and Resources:
Students will need access to the library or internet.

Procedures:
This lesson will introduce the idea of Life Cycle Assessment. The students will design a study that assesses products using a Life Cycle Assessment. The students will then choose a portion of the study for which to gather data.

Vocabulary:
Life Cycle Analysis:
An analytic technique used to evaluate the environmental impact of a material throughout its life cycle from extraction or harvesting of raw materials through processing, manufacture, transportation, use, and ultimate disposal or recycling.

Quantitative:
Expressed in terms of quantity, in other words, measurable. (For example, describing a friend one might say he is 5 feet 9 inches tall, weighs 170 pounds, and can run a mile in 8 minutes. His height, weight, and how fast he can run are all features that can be measured, or in other words are quantified.)
Life Cycle Assessment

As consumers, we often wonder, “Which is the more environmentally friendly product to buy?” There are many different ways to look at a product to determine how environmentally friendly it is. Researchers have figured out that the most thorough way to consider the environmental friendliness of a product is to look at its whole life or life cycle. Just like you have studied the life cycle of plants or animals, a product also has its own “life cycle.” This type of study is called a Life Cycle Assessment (it is also called a Life Cycle Analysis). A product Life Cycle Assessment means taking into consideration the entire range associated with the product including its manufacturing, transportation, use, and disposal or recycling.

Some examples of various aspects that a Life Cycle Assessment takes into account are:

• Base materials from which a product is made
  — Are they from renewable sources or nonrenewable sources?
  — If it is a renewable resource, is the resource gathered in a sustainable manner?

• The energy required to convert the base materials into the final product
  — How much energy is used?
  — Is the energy used renewable energy?

• Production process
  — Is solid waste generated during production?
    • If so, is the waste generated recycled or used for another purpose?
  — Is air pollution generated during the production process?
    • If so, what kind and how much?
  — Is water pollution generated during the production process?
    • If so, what kind and how much?

• Transportation of the materials and/or product
  — What type of transportation?
  — What type of fuel does the transportation use?
  — Does the transportation generate pollution?
    • If so, what kind and how much?
  — How many times does the product need to be hauled?
    • How far is the hauling distance –
      — from the base material to where the product is made?
      — from the product manufacturing to the consumer?

• End of product life (this means when the consumer is finished using the product for its intended purpose)
  — Can it be reused in a different way?
  — Can it be recycled?
  — Will it be disposed of?
    • Does disposal require special treatment?
How Would You Conduct a Life Cycle Assessment?

Let’s say that you and your friends are trying to convince the adults of the community to build a skate park. Since you just learned about carbon in school you have decided to conduct a Life Cycle Assessment to determine if building the skate park from wood or building it from concrete is the more environmentally friendly way to go. (Besides, then the adults can see you’ve been doing your homework and need to get outside for some exercise at the skate park).

How will you design a research project that considers the Life Cycle Assessment of different building materials? Recall what you have learned about the carbon cycle, including major sources for carbon emissions, and processes for carbon sequestration. Use the questions on the previous page as a guide for comparing your building materials. Think through all aspects of creating, using, and disposing of the products that will be used to build your skate park.

Step 1:
Identify the major parts that will be necessary to build the skate park using wood, concrete, or maybe a combination of both. Now generate a list of questions in regards to the Life Cycle Assessment for each building component. Your questions should be specific, and quantifiable. For example – How many miles do you have to travel to buy your wood building materials? Does the wood from the retailer come from a local sawmill? How far does the lumber have to be shipped to get from the sawmill to the retailer? Make a list of the same questions for the concrete building materials.

Step 2:
Now that you have your questions, you will need to do some research to find the answers. There is a lot of good information available in the library and on websites. However, you may need to take your research a step further by calling or emailing a company to find the latest information that is not yet available on the web. A company’s annual report can be a very good source of information. For example, a company’s website might state that it takes X amount of energy to generate a product and that they use 30% renewable energy to manufacture that product.
Guidance for Teachers

Considering the full life cycle assessment is quite an extensive exercise. Having students begin by writing out all of their questions will help them organize their research approach. Here are some thoughts on how to make the project a little easier to address:

- Have the students work together in groups and break up the research responsibilities.
- Make this a long term project and designate a small amount of time for class research each week. At the end of the semester, student groups can compile their information and give a class presentation on their findings.
- If time is limited, instruct the students to research a couple of the most relevant questions about the life cycle of their product. For example – compare just two aspects of the Life Cycle Assessment for the building products. How much carbon is emitted in the manufacturing process for each building product? Which building product stores more carbon?

Class discussions about the research process and results will develop critical thinking skills as students will learn how to compare one type of environmental burden with another.

Inevitably, students will find differing, perhaps even conflicting, information. This will enhance the conversation and will allow you to discuss the issue of assumptions vs. science based facts. Some of the aspects that the students could consider when trying to determine the source of differences are:

- Parameters for the study.
- Varying practices between companies.
  - Varying regulations in different states
- Different units of measure.

Overall this is a challenging exercise. It exemplifies the decisions we make everyday as consumers. However, many of the decisions we make are not based on this depth of assessment. Many times the information we use to make these decisions is not well defined. Small group or classroom discussions can explore the complexity regarding many of the product choices that we face on a daily basis.

Here are some examples of websites with Life Cycle Assessment information:

  then type “life cycle” into the search
- [http://www.corrim.org/pubs_list/](http://www.corrim.org/pubs_list/)
  The Athena EcoCalculator is a free download that allows instant access to Life Cycle Assessment information for different building designs. Registration is free and will allow students to analyze the environmental impact of building material choices for beams, floors, walls, and roofs.
- [http://www.epa.gov/greenbuilding/pubs/faqs.htm](http://www.epa.gov/greenbuilding/pubs/faqs.htm)

Also, be sure to periodically check The Forest Foundation website for updated links and information

- [http://www.calforestfoundation.org/](http://www.calforestfoundation.org/)
  The Carbon Curriculum and additional information will be available at the Tools for Teachers button (under Carbon Curriculum)