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.

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

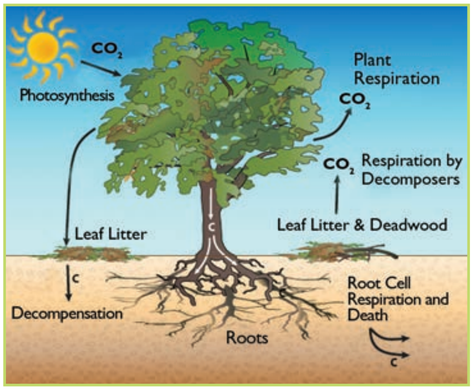
Objectives
By the end of this activity, students will be able to
- describe how forests help mitigate climate change; and
- compare the impact of sequestering carbon by different land-use types, such as pine forest, mixed forest, urban forest, cropland, and grassland.

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.

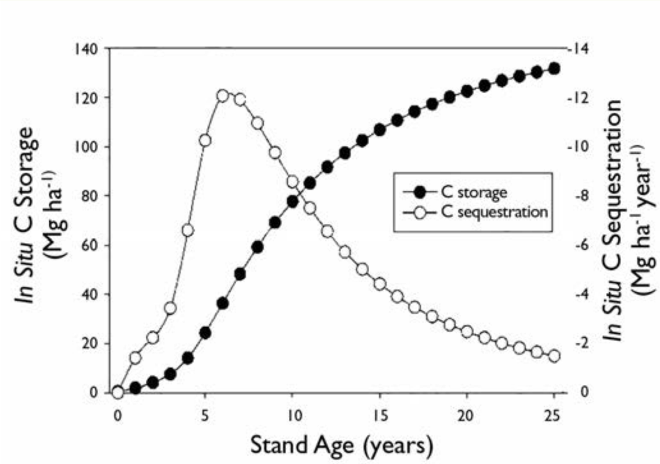


Figure 1. Carbon storage and carbon sequestration for a managed loblolly pine forest in Florida.

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

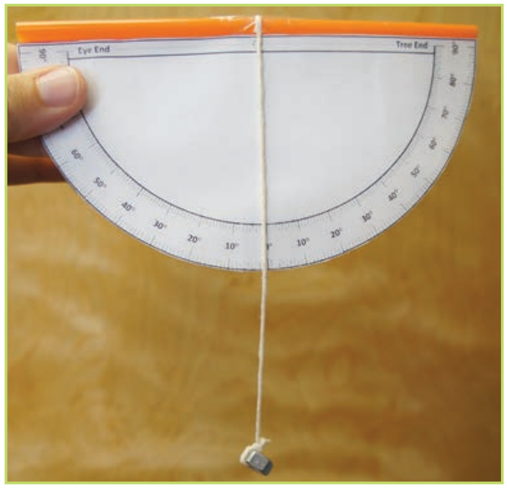
The Activity 8 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section3/activity8).

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.

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.

To continue exploring carbon sequestration, watch the Smithsonian Environmental Research Center's video, Ecosystems on the Edge: Forests and Climate Change.

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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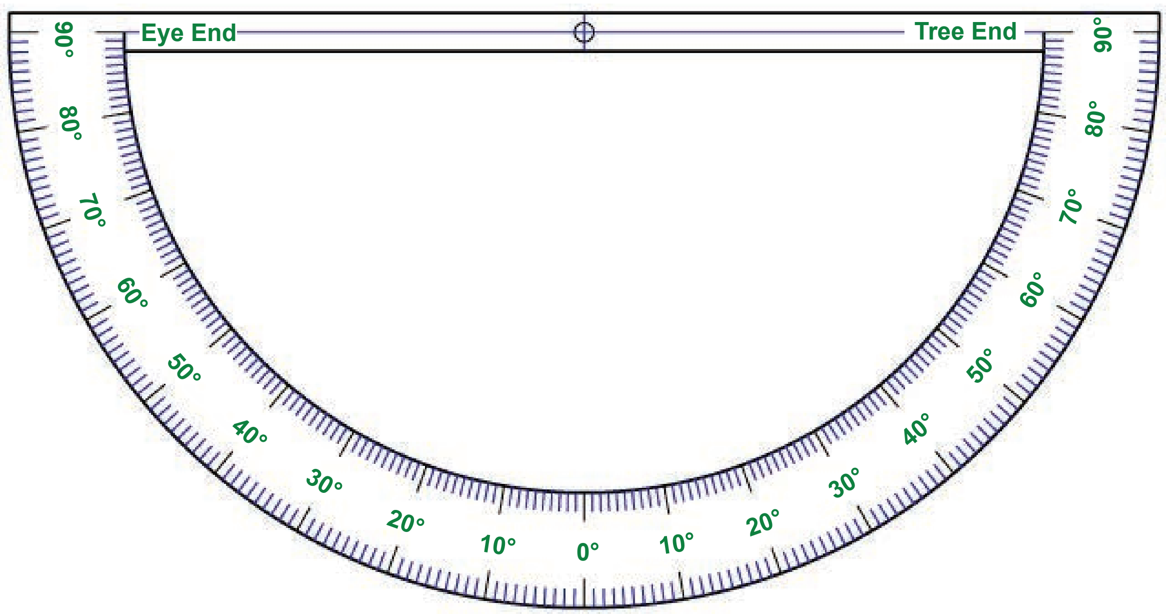
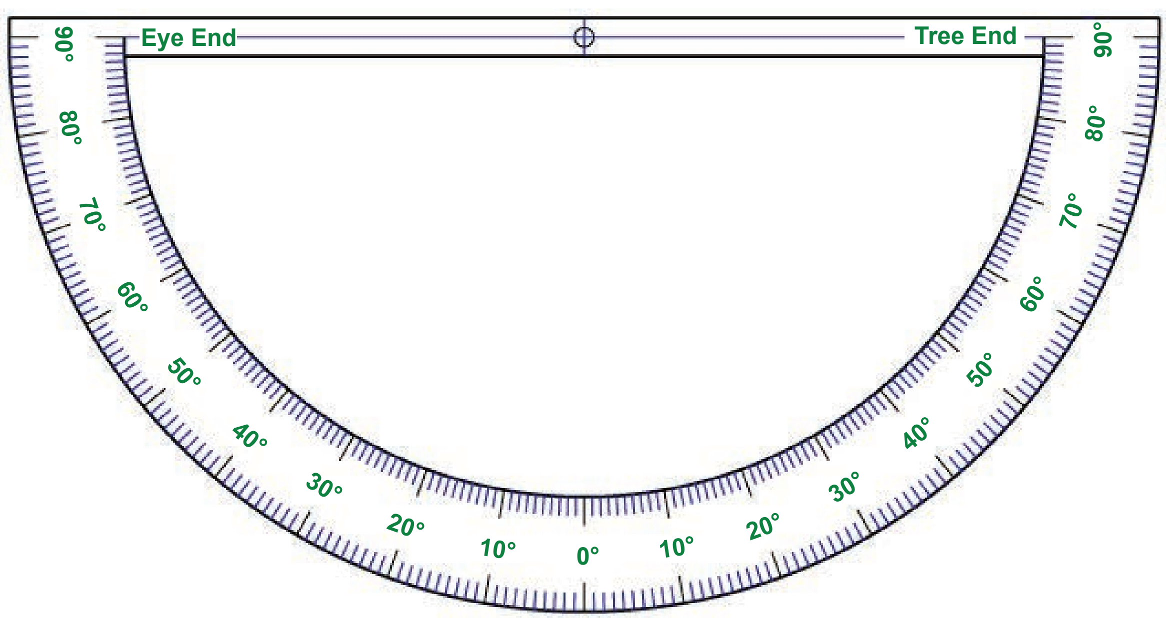
The National Tree Benefit Calculator allows students to enter a tree's location, size, and type of species, and then provides data on that tree's environmental and economic value.

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.

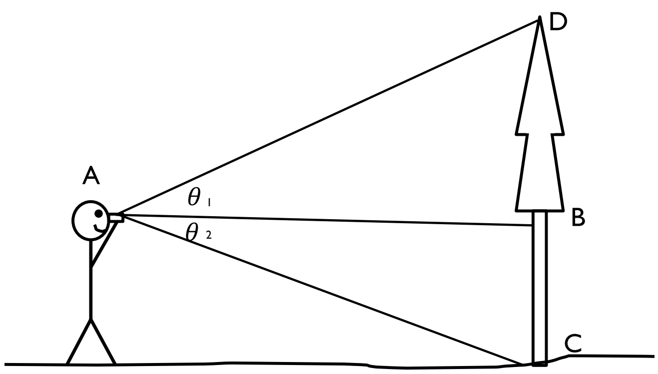
Data Table 2

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.



$$\tan\Theta_1 = \frac{DB}{AB} \qquad DB = AB\tan\Theta_1$$

$$\tan\Theta_2 = \frac{BC}{AB} \qquad BC = AB\tan\Theta_2$$

$$\text{Total tree height} = DB + BC = AB(\tan\Theta_1 + \tan\Theta_2)$$

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:

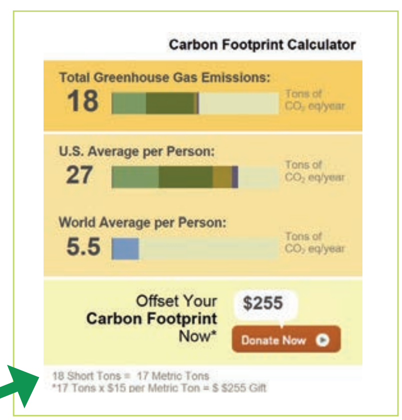
The carbon footprint of a person is the total amount of carbon emitted based on his or her daily actions and choices. A carbon footprint is measured based on factors such as fossil fuel consumption, food consumption, goods and services bought, as well as housing conditions. The Nature Conservancy has 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? ________________________

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).

$$\underline{\qquad\qquad\qquad} \times \frac{12}{44} = \underline{\qquad\qquad\qquad}$$

Average CO_2 emissions of group (tons/year) × 12/44 = 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) x 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)