Lesson 1: The Carbon Cycle

What are its implications for climate policy?

Question	What aspects of the carbon cycle must be considered in climate policy?
Age Level	High School
Objective	Students will explore aspects of the global carbon cycle that have implications for climate policy decisions. Students will present their knowledge using a creative medium. Students will reflect on what can be done to protect and enhance natural carbon sinks.
Time Needed	At least one 45-minute period

INTRODUCTION *(5 min)*

Most people are familiar with the concept of global warming. Most understand that carbon dioxide and other carbon-containing greenhouse gasses act like a blanket, trapping heat and raising the average temperature of the planet. Most people understand that human actions are contributing to increased levels of greenhouse gasses.

Many people, however, do not understand the global carbon cycle. What is it and how does it work? Why is it important? How have humans altered it? How has the planet responded to human-forced changes in the carbon cycle? What aspects of this are important to understand when making climate policy decisions?

This activity will give students the opportunity to explore these questions. This knowledge will lay the foundation for future explorations into climate policy.

Notes to Teachers:

- Some students may have heard that global warming is "junk science" or that there is a big debate over whether or not it is really happening. You can let them know that there is no debate about whether or not increased levels of heat-trapping gasses in the atmosphere will warm the planet. This is atmospheric physics. The only uncertainty lies in how much and how quickly the planet will warm.

EXPLAIN AND CONDUCT THE ACTIVITY *(20 min)*

Each student will receive a handout containing the following sections:

- What is the carbon cycle?
- The difference between short-term and long-term cycles
- The planet's carbon budget
- The "missing sinks"

STUDENTS DIVIDE INTO GROUPS OF EIGHT. WITHIN THE GROUPS:

- Students read the handout, taking turns reading aloud as the other group members follow along.
- After reading the entire handout, students divide into four pairs within each group.
  - Each pair takes responsibility for one of the four sections of the handout.
  - Pairs carefully re-read the section.
  - Each pair then discusses the reading, checking for comprehension.
  - Each pair then creates an original visual aid to explain and illustrate the concepts in the reading.
- Groups of eight reconvene. Pairs present their visual aid to the group, explaining core concepts.
- Groups of eight present their visual aids to the entire class.

ASK YOUR STUDENTS TO REFLECT AND SHARE ON THE FOLLOWING TOPICS *(10 min)*

- From the perspective of climate policy, what are important differences between short-term and long-term cycle carbon? Ideas include:
  – Burning biofuels releases carbon that was most recently in the short-term carbon cycle.
  – Burning fossil fuels releases carbon that was most recently in the long-term carbon cycle.
  – Energy made from carbon in the short-term carbon cycle does not contribute additional carbon to the short-term carbon cycle. This contrasts with the burning of fossil fuels which adds carbon to the short-term cycle. (Note: If fossil energy is used to produce biofuels, the greenhouse gas savings of biofuels are reduced. If large amounts of fossil energy is used to produce biofuels, the biofuels may not provide any greenhouse gas reduction benefits.)
- What are the implications of taking carbon from the long-term cycle and adding it to the short-term cycle? Ideas include:
  – Burning of fossil fuels adds carbon to the short-term cycle more quickly than the short-term cycle can remove it.
- What is the significance of carbon sinks in relation to climate change? Ideas include:
  – Carbon sinks remove carbon from the atmosphere.
  – Without carbon sinks, carbon would accumulate in the atmosphere instead of continuing through the carbon cycle.
  – Carbon sinks buffer the accumulation of carbon in the atmosphere from the burning of fossil fuels.
  – Plants and soil store large amounts of carbon which is typically released when land is tilled for growing crops.
- How could climate policy be designed in a way that would use an understanding of the carbon cycle to reduce atmospheric concentrations of greenhouse gasses? Ideas include:
  - Policy could encourage the enhancement of natural carbon sinks, for example by promoting reforestation and better agricultural practices.
  - Policy could provide incentives to develop low carbon biofuels using carbon from the short-term carbon cycle or other renewable energy sources.
  - Policy could discourage the burning of fossil fuels and/or promote development of technologies to minimize the emissions from the burning of fossil fuels.

EXTEND THE LEARNING *(10 min)*

Read the following passage to your students:
Chris Field is a scientist and an author of the “State of the Carbon Cycle Report” released by the U.S. Climate Change Science Program in November 2007. Field explains how in North America, carbon sinks, such as forests regrowing on former farmland, may be removing up to half of the carbon North Americans emit every year from the burning of fossil fuels. These natural sinks sequester (store) carbon and keep it out of the atmosphere.

"In effect, we have been getting a huge subsidy from these unmanaged parts of the carbon cycle," states Field. The buildup in the atmosphere of greenhouse gasses has been far less than it would have been if it weren't for the amount of carbon uptake by the plants, soils, and oceans.

Field's report found, however, that the ability of natural carbon sinks to continue storing carbon may be jeopardized. As the forests mature and as climate conditions change, the carbon sinks may reach their limit. They may also release their limit if drought and wildfires become more frequent, as some climate simulations predict.

It is not just North American forests that are in danger of losing their ability to absorb carbon. When threatened by drought, trees in the Amazon rainforest die, releasing massive amounts of carbon. Leeds University professor Oliver Phillips warns, "For years the Amazon forest has been helping to slow down climate change. But relying on this subsidy from nature is extremely dangerous. … If the earth's carbon sinks slow or go into reverse, as our results show is possible, carbon dioxide levels will rise even faster."

One of the other major carbon sinks, the Southern Ocean surrounding Antarctica, is also weakening. The ocean's ability to absorb carbon dioxide has declined by about 15% per decade over the past 25 years and it will be less efficient in the future.

Co-chair of the Global Carbon Project, Dr. Mike Raupach cautions, "While these natural $C0_2$ sinks are a huge buffer against climate change, which would occur about twice as fast without them, they cannot be taken for granted."

Sources:

"Amazon Rainforest Carbon Sink Threatened by Drought." Science Daily. March 9, 2009: <http://www.sciencedaily.com/releases/2009/03/090305141625.htm>.

"Carbon Sinks Losing the Battle with Rising Emissions." Science Daily. March 16, 2009: <http://www.sciencedaily.com/releases/2009/03/090317094729.htm>.

"First ever 'State of the Carbon Cycle Report' Finds Trouble." Science Daily. November 17, 2007: <http://www.sciencedaily.com/releases/2007/11/071114111141.htm>.

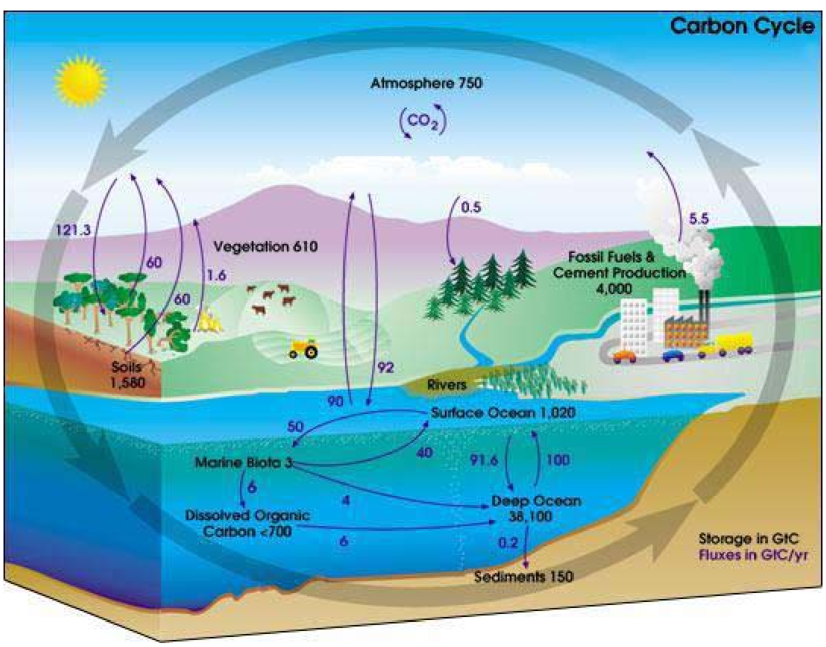
"Southern Ocean Carbon Sink Weakened." Science Daily. May 19, 2007: <http://www.sciencedaily.com/releases/2007/05/070517142558.htm>.

ASK YOUR STUDENTS TO REFLECT AND SHARE THOUGHTS ON THE FOLLOWING QUESTIONS:

- What might be the implications of natural carbon sinks slowing or reversing their uptake of carbon? Ideas include:
  – Increasing rates of accumulation of greenhouse gasses in the atmosphere.
  – Increased rates of global warming.

- What implications would this possibility have for policy decisions? Ideas include:
  - Policies could encourage enhancement of natural carbon sinks.
  - Funding could support continued research into ways to protect and enhance carbon sinks.
  - When setting targets for emission reduction, policy makers could consider the possibility that carbon uptake may slow.
- What could be done to help increase natural carbon sinks? Ideas include:
  - Planting trees
  - Slowing deforestation
  - Adopting better agricultural practices
  - Gaining more knowledge about how to protect and enhance carbon sinks

HOMEWORK:
While the thoughts are fresh, each student should keep a journal about opinions and thoughts raised by the lesson. The journal will serve as the starting point for each student to craft a position statement. The position statements will cover topics from each lesson. The more specific details each student includes in his or her journal, the easier it will be to write a position statement. A recommended format would be to record several ideas or opinions, each with at least three supporting statements, based in concepts presented in the lesson.



HANDOUT

WHAT IS THE CARBON CYCLE?

Carbon (C) is the basic building block of life (many nonliving things contain carbon too). Carbon is the fourth most common element in the universe (after hydrogen, helium and oxygen). Every organism needs carbon for structure, energy, or both. Humans use carbon for both energy and structure—in fact the human body is about half carbon (not counting the water).

Carbon atoms are not created or destroyed—they move from one form to another. The carbon in your body was most recently part of a plant or an animal that you ate. Before that plant or animal consumed the carbon, it was in the atmosphere as a molecule of carbon dioxide. You release carbon when you exhale, or go to the bathroom, or get a haircut. When you die and decompose, you release all your stored carbon.

On a global scale, carbon moves between the atmosphere, the oceans, the biosphere (the living organisms on the planet—including you), and the geosphere (the rocks, sediments and fossil fuels).

Anything that adds carbon to the atmosphere can be called a "source." Anything that removes carbon from the atmosphere can be called a "sink."

THE DIFFERENCE BETWEEN SHORT-TERM AND LONG-TERM CYCLES

Short-term carbon cycles involve carbon that moves through living organisms. It operates on a time scale of days to thousands of years. Plants use solar energy to drive the process of photosynthesis where they combine carbon dioxide from the atmosphere with water to produce sugars and oxygen. Plants and animals "burn" these sugars to get energy to grow. The process of burning the sugars releases some carbon back to the atmosphere as carbon dioxide (this is called respiration). As the organisms grow, they store carbon in their tissues. When they die, they release their carbon to the soil, to the ocean floor, or the atmosphere.

The long-term carbon cycle involves carbon stored in rocks and fossils. It operates on a timescale of millions of years. Rainwater reacts with minerals in rocks and soils on the earth's surface, slowly weathering them. The weathered substances travel through streams and rivers to the ocean where they are deposited on the ocean floor and eventually form rock. As the ocean floor spreads and is pushed under the continents, the rock that was the ocean floor gets pushed deeper and deeper. As it gets deeper into the earth, it heats up, melts, and can rise back to the surface, releasing CO_2.

The long-term carbon cycle also includes fossil fuels. The carbon in fossil fuels comes from plants and animals that were living long ago. When they died and were buried, their bodies eventually turned into coal and petroleum.

THE PLANET'S CARBON BUDGET

It may be helpful to think of the earth as having a carbon "budget." As with financial budgets, the ideal is to have it balanced. For a carbon budget, balanced would mean that all the carbon produced by sources would be taken up by sinks.

When humans burn fossil fuels, we release carbon into the atmosphere. Humans also release carbon into the atmosphere when we clear forests for agriculture. We are currently adding carbon more quickly than the planet's natural sinks can remove it. This extra carbon accumulates in the atmosphere (contributing to global warming).

LET'S RUN THE NUMBERS:

- Sources: Burning fossil fuel releases about 5.5 GtC (gigatons of carbon) into the atmosphere each year. Deforestation and other land-use changes relase about 1.6 GtC a year. This totals around 7.1 GtC a year.*
- Sinks: Scientists can measure that approximately 2 GtC diffuses into the ocean each year.
- The difference between sources and sinks is 5.1 GtC.

So, if you assume that the land absorbs about as much carbon each year as it releases, you might expect that the amount of carbon in the atmosphere would increase each year by about 5.1 GtC. It turns out, however, that the amount of carbon in the atmosphere increases each year by only about 3.2 GtC.

Where, you might ask, is the 1.9 GtC that is unaccounted for? Remember, carbon is not destroyed—it just moves from one form to another through the carbon cycle.

THE "MISSING SINKS"

Scientists have been trying to figure out where the missing 1.9 GtC goes each year. Evidence points to the land surface. What, however, could be causing the land to take up more carbon than it releases each year?

One possible explanation is that forests are regrowing over much of the northern hemisphere. Over the last century much of the northern hemisphere was heavily deforested. It is now regrowing. Young, rapidly-growing trees take carbon from the atmosphere through photosynthesis and store it in their new wood.

Another possible explanation is that climate changes are causing the earth surface to take up more carbon than it releases. For example, extended growing seasons, trees growing further north in the Northern Hemisphere, and higher concentrations of CO_2 in the air could be contributing to increased growth of plants.

Scientists are working to understand where and how this extra carbon is being taken up by the earth's surface. A better understanding of these complex biogeochemical processes can help scientists protect and enhance the ability of these sinks to continue absorbing carbon.

Source:
"The Carbon Cycle : Feature Articles." NASA Earth Observatory.
<http://earthobservatory.nasa.gov/Features/CarbonCycle/printall.php>.

*Note:
As of 2009, annual human-caused emissions of carbon dioxide are about 8 GtC, not 7 GtC. Emissions are projected to continue to rise.