Science Unit: ***Climate Change***
Lesson 6: ***Carbon Cycle***

School year:	2008/2009
Developed for:	Shaughnessy Elementary School, Vancouver School District
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Grade level:	Presented to grades 5 - 7; appropriate for grades 4 to 7 with age appropriate modifications.
Duration of lesson:	1 hour and 10 minutes
Notes:	Ideally, requires three adults to animate.

Objectives

1. Explore the five main reservoir of carbon on Earth: the atmosphere, the biosphere, fossil fuels, oceans and sedimentary rocks (limestone).
2. Discover the processes by which each reservoir absorbs atmospheric CO_2.
3. Discover the processes by which reservoir releases CO_2 in the atmosphere.
4. Appreciate that this cycle is dynamic, and that the rates of exchanges can change as the climate changes – which can lead to positive or negative feedback loops.

Background Information

In this activity, we concentrate on five main reservoirs of the carbon cycle. To each reservoir will correspond a station (except the biosphere and fossil fuels, which will share the same station), with an activity, an experiment, or samples to observe. The students, pretending to be carbon atoms, move from one reservoir to the other. To do so, they must learn about the processes that allow carbon to flow from the atmosphere to the reservoir, and from the reservoir back into the atmosphere. Here is some info on the 5 carbon reservoirs we will be dealing with:

Reservoir 0: The Atmosphere [contains about 800 billion tons of carbon]. Carbon is stored as carbon dioxide, CO_2 (and minimal quantities of carbon monoxide CO). As of January 2007, the concentration of CO_2 is about 0.0383% by volume (383 ppmv, sometimes just noted ppm). This represents about 2996 billion tons of CO_2 (so about 800 tons of carbon, since for 3.66 g of CO_2 you get 1g of carbon and 2.66g of oxygen), and is estimated to be 105 ppm (37.77%) above the pre-industrial average. Note that an increase in CO_2 concentration of 1 ppmv of CO_2 correspond to 2.12 billion tons of carbon (GtC) added to the atmosphere – this allows you to related emissions to changes on atmospheric concentrations.

Reservoir 1: The Biosphere [contains about 1900 billion tons of Carbon]**:** Composed of all living organisms, on land or in water, including plants, which capture carbon by photosynthesis, and all other animals that feed on them. This links nicely to the concepts of foodwebs and f;ow of energy (and carbon!) through the food chain, from producers, to herbivores, to carnivores, to decomposers… It's good to stress that although we are most familiar with the land biosphere, the same kind of structure exists in the oceans, with phytoplankton at the base of the food chain.

Process to enter: photosynthesis ($6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$**)**

Processes to exit:
a. respiration, decomposition, combustion. Note that all these processes are essentially the same, happening at different speed and facilitated by different catalysts. Basically it's the reverse of photosynthesis: long chains of carbon are turned into CO_2 and water, releasing energy. Interesting to point out that a lot of the mass of the food we eat we loose by respiration, as we breathe out CO_2 after "burning" long carbon chains to get energy!
b. Burial and fossilization: see below.

Reservoir 2: Fossil fuels [contain about 20,000 billion tons of carbon**]**

Process to enter: Burial and fossilization: This is another possible route for organic matter. Plankton can be trapped in ocean sediments, and over geological time they turn into crude oil. Plants can be trapped in soils, and over geological times convert into coal. Coal and oil are fossilized organic matter, which is why we call them fossil fuels. They are made of long chains of carbon that still contain the sunlight energy they trapped when they were created by photosynthesis. When human dig them out and burn them, we tap into reservoirs of stored solar energy. We accelerate the decomposition (combustion) of organic carbon chains that have been stored for millions of years.

Process to exit: natural decomposition is one, but mining and combustion by humans is currently dominant.

Reservoir 3: Ocean Water [contains about 36,000 billion tons of Carbon**]:**

"There is an exchange of carbon dioxide between the atmosphere and the ocean's surface. Carbon dioxide dissolves in the ocean and provides the source of carbon dioxide that plants and plankton living in the ocean rely on for photosynthesis. The amount of carbon dioxide the ocean can contain depends on the temperature of the water and on its saltiness (whether it is sea water or fresh water). Cold water can hold more carbon dioxide in solution than warm water. When carbon dioxide dissolves in water, it forms carbonic acid which makes the water acidic. In the lab we can test for the acidity caused by the presence of dissolved carbon dioxide using Universal Indicator, which turns yellow when the solution is acidic. This activity tests whether sea water or fresh water absorbs more carbon dioxide. Sea water can absorb more carbon dioxide than fresh water without having major environmental effects. [2]*"*

More in details..

"When CO_2 *enters the ocean, it participates in a series of reactions which are locally in equilibrium:*

Solution:

$$CO_2(atmospheric) \rightleftharpoons CO_2(dissolved)$$

Conversion to carbonic acid:

$$CO_2(dissolved) + H_2O \rightleftharpoons H_2CO_3$$

First ionization:

$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ (bicarbonate ion)

Second ionization:

$HCO_3^- \rightleftharpoons H^+ + CO_3^{--}$ (carbonate ion)

This set of reactions, each of which has its own equilibrium coefficient determines the form that inorganic carbon takes in the oceans. […] In the ocean the equilibria strongly favor bicarbonate. Since this ion is three steps removed from atmospheric CO_2, the level of inorganic carbon storage in the ocean does not have a proportion of unity to the atmospheric partial pressure of CO_2. The factor for the ocean is about ten: that is, for a 10% increase in atmospheric CO_2, oceanic storage (in equilibrium) increases by about 1%, with the exact factor dependent on local conditions. This buffer factor is often called the "Revelle Factor", after Roger Revelle. [1]"

Process to enter: dissolution.

Processes to exit: exsolution and absorption by shell-producing zooplankton (see below).

Reservoir 4: Sedimentary Rocks, (or limestone) [contains about XXXX billion tons of Carbon; biggest reservoir**]:**

"Many organisms living in the ocean use the dissolved carbon dioxide to make calcium carbonate ($CaCO_3$) shells. Some of these organisms are large and easy to see (for example, clams and snails), but most of the carbonate shells are produced by the microscopic creatures called plankton.

Floating in all the oceans of the world, plankton absorb vast quantities of carbon in their shell-building activities. They do not live long though. In some places, when they die, their shells fall to the bottom of the ocean floor to form sediments of limestone and chalk. Raised above sea level by tectonic activity, the sediment often forms large rock formations. The white cliffs of Dover are gigantic chalk cliffs originally formed from these types of sediment. Natural chalk is mined from such formations.[3]"

Process to enter: Zooplankton form carbonate shells. They die, sink, and accumulate at the bottom of the ocean and form limestone.

Process to exit: formation of mountains and uplifting by tectonics forces brings sedimentary rocks to the surface. Their weathering releases slowly the stored carbon. This is what happens in accelerated when we mix vinegar and calcium bicarbonate (baking soda); the carbon in the baking soda reacts with the water in the vinegar and CO_2 is released. This process is very slow. Carbon dioxide stored in sedimentary rocks is also liberated when there are volcanic eruptions.

Vocabulary

Word:	Brief definition.
Fossil fuels	Coal and petroleum are fossilized plants that still contain the long carbon chains produced by photosynthesis. When they are burned, these chains are broken down and the stored sunlight energy is released. The carbon returns to the atmosphere as carbon dioxide.

Materials

- “Souvenirs”: something for each student to collect at each reservoir. They can use them to teach other (parents?) about the carbon cycle…
- Reservoir 1 souvenir: pieces of wood or seed of some sort (purple runner beans work great)
- Reservoir 1: picture evoking photosynthesis and food-webs.
- Reservoir 2: sample of coal, and, if available, crude oil.
- Reservoir 2: blankets to represent burial
- Dissolution experiment (reservoir 3) Each group of pupils will need…
- Eye protection
- 2 beakers
- Reservoir 2 souvenir: piece of wood coal
- Reservoir 4: pictures of shell-forming zooplankton, some sea shells, samples of limestone, and a few marine fossil samples if available.
- Universal Indicator solution
- Reservoir 3 souvenir: sea water in a small test-tube
- Reservoir 4: baking soda and vinegar, and maybe a little volcano model made of clay or plasticine
- Reservoir 0 (atmosphere): balls to represent oxygen?
- Sea water (If real sea water is unavailable, a substitute can be made by dissolving approximately 30 g of sodium chloride in 1 dm^3 of water.)
- Reservoir 4 souvenir: sea shell or limestone sample
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- Tap water (fresh water)
- Drinking straw

In the Classroom

Introductory Discussion

1. Short description of ‘hook’ to capture student’s attention.
   - Review on energy budget: what is the role of greenhouse gases? What are the main ones? ($H_2$2O, methane, CO_2)?
   - What roles to cars and industry play in the current climate change crisis? [they emit CO_2]
   - Are they the only thing that emit CO_2? Are there also natural sources?... [decomposition and respiration emits CO_2, volcanoes…]

2. Short description of other items to discuss or review.
   - You know about the water cycle. Can someone summarize it? What are the different places where water is? We call those reservoirs. How does water move from one reservoir to another? Just like water moves from different reservoir, so does carbon. But one difference is that while

water keeps the same molecular form (H_20) when it moves from a reservoir to the next, carbon moves from different molecular structure in each reservoir. Today, we will learn about the carbon cycle, its different reservoirs, in what form is carbon stored there, and how carbon flows from one reservoir to anther. The best way to do so is for you to become an atom of carbon and do the journey yourself… in this game, you will flow from different reservoirs and learn about the different processes that allow you in or out of that reservoir. In each reservoir carbon takes a different form. To remember these, you will collect pieces of carbon in each form. You will also draw a map of your journey through the carbon cycle. To enter a reservoir, you will have to do a game, or an experiment. Then you will learn more about that reservoir. To move to the next reservoir, you will have to answer a riddle!

- You will start your journey in the atmosphere, in the form of carbon dioxide. This is the reservoir we are the most concerned with, because CO_2 controls our temperature… The atmosphere now contains about 800 billion tons of carbon. Before the industrial revolution, it contained only about 600 billion tons – the 200 extra were emitted mainly by humans. Each year, human emits 9 more billion tons of carbon in the atmosphere. Where does it goes? Does it stay in the atmosphere? We need to know, so we can predict how the climate will change. So we need to understand the carbon cycle… and that's what you will do today!
- So you will start your journey in the atmosphere. But before you can leave you must answer some questions! What molecular form are you? [CO_2!] is that a solid, a liquid or a gas? [a gas!], Because you are a gas, you are allowed to walk and move. You carry 2 atoms of oxygen (balls, sand bags, or other). In other reservoirs, you will be converted to solids or liquids, and you will have to sit again. Here is your first tool: the map you will follow and fill (give out carbon cycle map).

3. Briefly describe science experiment/activity.

    - This activity is framed as a game, where the students pretend to be carbon atoms and move themselves from a reservoir to the next. There are 3 stations, animated by 3 persons. The students are split into 3 small groups and each one circulate between the 3 stations. Alternatively, if the group can stay together, the three stations can be done sequentially, animated by one person.
    - Students are given a map of the carbon cycle that they will have to complete. Along their journey in the carbon cycle, they will collect "souvenirs" of each reservoir they have gone through. These are small object they collect and keep, which can be used as props for them to teach the carbon cycle to someone else.

4. Briefly describe the processes of science that the students will focus on

    Mainly observation. Also modelization, as they are abstractly reducing the whole carbon cycle in terms of a few reservoirs and flows.

Science Activity

<u>Activity Title</u>: Carbon Cycle Game

<u>Purpose of Activity</u>: explore the four main reservoirs of carbon (biosphere, fossil fuels, oceans, sedimentary rocks) and the processes by which they absorb atmospheric CO_2 (respectively: phytosynthesis, burial and fossilization, dissolution, and burial of shell-forming zooplankton) and release

CO_2 in the atmosphere (respectively: respiration/decomposition/combustion, decomposition/combustion, exsolution, and volcanic eruptions and erosion).

Methods and Instructions:

Station one: **Biosphere and fossil fuels**. Photosynthesis and decomposition and Reservoir 2: fossil fuels. First, a recap on photosynthesis. What happen during photosynthesis? So you are now CO_2 molecules… how will you look like after photosynthesis? (guide the students to form a long carbon chain, and release their oxygen atoms.) You are now no longer gaseous, but solid! So you sit to represent that…

- Welcome to the biosphere! …(brief recall of the flow of energy in the biosphere – food chain. Carbon also flows in this chain! Where are you in the food chain? Do you have carbon in you? (protein, sugars, fats, bones, all contain carbon).) Remind them that this happens also in the sea..
- How does carbon leaves the biosphere? [respiration decomposition -> return to the atmosphere]. Student get their wood sample.
- .. but also, if it gets buried for a very long time it can move to another reservoir: **fossil fuels.** (students are covered with blankets to represent that, and they are shown samples of coal and crude oil and explain how they were formed).
- Students answer question ("So what is the other way carbon gets out of the biosphere reservoir? They move they to which reservoir? [burial and fossilization-> fossil fuels in the Earth]. And how do they leave that reservoir?... humans mine and burn: very fast! Or they decompose very slowly… [students get their coal "memory" and move on to station two]

Station two: **Oceans**. Dissolution experiment.

- You are about to enter a new reservoir: the ocean. Do you know of any familiar places where carbon is stored in water? [carbonated beverages! pop-bottles!] When carbon dissolved the water of our pop-beverages, it forms a weak acid called carbonic acid. It is similar in the oceans. It's good news and bad news for us. It's good news because some of the CO_2 we emit might get absorbed by the ocean. It's bad news because the extra CO_2 could make the oceans more acidic, and that could harm the fishes and plankton that grow in it. To investigate this effect we will do a small experiment! We will dissolve CO_2 in fresh water and in sea water, and see which can store the more CO_2 without changing its acidity.
- *"The students should work in pairs or small groups. They pour 100 c^{m3} of sea water into one beaker and 100 c^{m3} of fresh water into the other (to accelerate things these can be prepared in advanced by the person taking care of that station). Then they add several drops of Universal Indicator to each so that the colour is clearly visible. Next, using the straw, they blow gently and consistently into the water samples - first the sea water, then the fresh water. For each they time how long it takes the indicator to become yellow and record the results.*
- *When this is done, the students should answer the following questions:*
- *Q 1. What did it mean when the indicator was yellow? = That carbon dioxide had dissolved in the water to produce an acid.*
- *Q 2. Which beaker of water turned yellow the quickest? = The beaker of fresh water.*
- *Q 3. Which absorbs more carbon dioxide without its acidity changing? = Sea water.[2]"*

- Students having done this task and answered some questions are allowed “into” that reservoir. They are now dissolved in water they should show their water sample and walk doing the wave to represent that. They get their sea water sample and move on to station three…

Station three (reservoir 4) **sedimentary rocks**: …You are about to enter the biggest of the reservoir of carbon, and also the most stable, the most long lasting: sedimentary rocks! Limestone is made of carbon and other atoms like calcium. But how will you enter this reservoir? What process transforms the dissolved CO_2 that you are to turn into rock?... sit down and listen to the strange story of limestone. As you are moving in the water, dissolved, you notice these strange creatures! (show pictures of zooplankton). In real life, they are so small you can’t see them with the naked eyes. You need a microscope. What are they? [zooplankton!] As hard as it is to believe, they are the answer to our question. What do these three have in common? (Show a sea shell looking like a snail, the zooplankton picture, and a clam shell) [they have solid shell]. This shell is made of carbon! (see info above for detail). Show samples of fossils to llustrate how these shells turn into rock. Baking soda and chalk are is made of ground up limestone,

- OK so now you are in the biggest reservoir of carbon on earth: sedimentary rocks. Do you stay here forever? Is this the end? Who remembers the rock cycle?...
    - Sedimentary rocks get exposed and react with water to create CO_2 again, which is released into the atmosphere. This is veeeerrry slow…
    - A faster way out is through a volcanic eruption. In the rock cycle, sedimentary rocks are metamorphosed and eventually melted back into igneous rocks. The carbon that was stored is also there, and it a lot of CO_2 is liberated when there is a volcanic eruption…. Mix vinegar and baking soda in volcano model to illustrate!

Closure Discussion

1. Go back to original question: where goes the 9 GtC humans emit every year? Complete the carbon cycle map as student give suggestions. This serves as a revision. Then reveal the actual numbers: about 3 GtC is absorbed by land biosphere, and 2 GtC by oceans. That leaves 4 GtC accumulating in the atmosphere each year…
2. How will that change in the future? Will the land and ocean continue to absorb more than they emit, thus partly compensation for our extra emission? Or is it possible they will start emitting more than they absorb… increase in temperature will increase the rate of decomposition, thus possibly driving the biosphere to emit more CO_2…

Other possible questions (from ref 2):

3. Q 1. Carbon is in the cycle in solid, liquid and gas forms. Which products show each of these forms (give one example of each)? = *For example; atmosphere – CO_2, sea water, dissolved hydrogencarbonate ions (HCO_3^-), coal – almost solid carbon, or limestone - $CaCO_3$.*
4. Q 2. Which processes happen quickly (give examples)? Which ones happen very slowly (give examples)? = *For example; quick processes – respiration, combustion, slow processes - limestone and coal formation.*
5. Q 3. Which processes are going on outside the window today? = *For example; photosynthesis, respiration, CO_2 dissolving in rain (if it is raining), weathering, consumption, excretion and death.*
6. Q 4. Which processes do you take part in? = *Respiration, consumption, excretion and death.*

References

1. http://en.wikipedia.org/wiki/Carbon_cycle.
2. http://www.rsc.org/education/teachers/learnnet/jesei/oceans/index.htm
3. http://www.ucar.edu/learn/1_4_2_16t.htm.
4. http://www.radix.net/~bobg/faqs/scq.CO2rise.html (a bit outdated but a good summary)

Extension of Lesson Plan

1. For older kids, the lesson could include information on the molecular structure of carbon in each form. They could work with ball-and-springs atomic models to create the right molecules for each reactions, using the different reactants.

THE CARBON CYCLE!