Activity 12: The Carbon Puzzle
Tracking Carbon Presentation: Teacher Notes

Slide	Notes
1	This presentation provides a step-by-step explanation of a graph that combines several carbon pools. It describes each carbon pool and how they combine to build the final graph.
2	By mass, carbon is the fourth most abundant element in the universe. Carbon is found many places on Earth including the atmosphere, water bodies, and the biosphere.
3	Many things contain carbon including soil, trees, plants, animals, coal, oil, and diamonds. Can you think of more places where carbon is found? Because carbon is a part of most organic molecules, such as cellulose, sugar, fats, proteins, and enzymes, carbon is in all living things.
4	Carbon is found within different pools, such as plants and the atmosphere, and carbon also moves between pools. For example, carbon moves from the atmosphere to plants through the process of photosynthesis. This diagram shows the natural carbon cycle with human changes, such as fossil fuel combustion and land conversion. In land conversion, trees are removed from a landscape for development, agriculture, or other reasons without replanting them. This process is called "deforestation." The Exploring the Carbon Cycle video on the Activity 7 webpage explains this diagram. You can either click the diagram to access the video, or go to the following link: http://www.youtube.com/watch?v=PV1ac6gFyRY&list=PLgM-uU3vOAbIVCkFxqkwGNQPkRL0Rs7gl&index=7.
5	Most carbon in the atmosphere is in the form of carbon dioxide, CO_2. (Methane, another importance greenhouse gas, also contains carbon.) Since the 1960s, scientists have taken consistent measurements from a mountaintop in Hawaii and noted a steady increase in atmospheric carbon dioxide at that location. Scientific researchers and agencies also measure (and average) CO_2 at other locations as well to determine average global concentrations. The annual ups and downs show the work of plants in the northern hemisphere, which sequester carbon every summer and release it every winter.
6	Earth's natural carbon cycle is in balance. Some processes add carbon to the atmosphere, and others remove carbon from the atmosphere. Carbon dioxide in the atmosphere captures long-wave radiation that is re-radiated from Earth after it is heated by the shortwave radiation from the sun. This keeps Earth at the appropriate temperature to support current life forms. Humans have changed this balance so that there is now more carbon in the atmosphere than there has been in past 800,000 years. As a result, more heat is trapped in the atmosphere, and Earth's global average temperature is increasing.
7	Here is a simple model of the carbon cycle with round numbers for the amount of carbon in major carbon pools and the amount of the carbon that moves among these pools every year. The major pools are the atmosphere, plants and soil, the oceans, and fossil fuels. The amount of carbon in the pools is shown in petagrams (a petagram is one quadrillion grams or one trillion kilograms), and the carbon moving between the pools is shown in petagrams per year.

	The unit "petagram" is used here because of the size of these global stocks of carbon. Both blue boxes represent the ocean, with the top box representing the surface ocean and the bottom box representing the deep ocean. Notice that the amount of carbon going into the atmosphere from the plants and soil box is 1 to 2 petagrams more than the amount of carbon going from the atmosphere to plants and soil. This is the result of deforestation. Also notice that 6.5 petagrams of carbon per year move from the fossil fuel pool to the atmosphere. This occurs through the combustion of fossil fuels and adds carbon to the atmosphere, indicated by the plus sign (+) in the atmosphere box. This makes for a total increase of 7.5 to 8.5 petagrams of carbon in the atmosphere every year. This may not seem like a lot, so it might help to put this measurement into more familiar units. A petagram is equal to one billion metric tons. A metric ton equals 1,000 kilograms. One kilogram equals 2.205 pounds. This means that 1 petagram equals 2.2 trillion pounds, and 7.5 petagrams equals 16.5 trillion pounds!
8	If we want to reduce carbon dioxide in the atmosphere, we could make the inputs smaller or the outputs bigger. Both of these actions have costs and potential consequences.
9	In what areas should scientists and engineers be working to most effectively and efficiently reduce carbon emissions or increase carbon storage? • Although the ocean is a huge carbon sink, increased carbon in the sea causes a chemical reaction that converts this carbon to carbonic acid and changes the pH of the ocean, which isn't so good for the coral and shellfish. We probably don't want to increase the >100 in the blue circle. • While planting more trees is certainly helpful, it requires a lot of land. Wildfire, hurricanes, and other events that can damage or destroy trees are hard to control, so it is difficult to reduce the amount of carbon "exhaled" from forests under these circumstances. Changes in the marketplace affect when landowners harvest trees and for which markets. People are working on adding to the 100 in the other blue circle, and to reducing the >100 in the red circle. These are areas of current research and technology and can lead to additional benefits like habitat for wildlife, improved water quantity and quality, and reduced noise. • Finally, we can reduce emissions from fossil fuels (6.5 in red) though finding adequate energy substitutes for fossil fuels can be difficult and costly.
10	The first part of this activity is a puzzle to explore forests' contributions to the carbon cycle. There are three possible ways forests influence carbon: one is obvious, but two are less so. Students will participate in a cooperative learning exercise to figure out the answer to the puzzle. **Stop the slide show and allow the student groups to complete the Six Bits puzzle.**
11	After groups have determined their answers, you can use this slide to talk about their solutions. • When more forests sequester carbon, the 100 in the circle gets bigger. • When we use wood products, that 100 stays sequestered and does not go back to the

	atmosphere. • When we substitute wood for fossil fuel-intensive products, we reduce the 6.5 number.
12	While this image can help us visualize the role of trees in the carbon cycle, it does not explain wood products or wood substitution. Carbon sequestration is the process of transferring atmospheric carbon dioxide into other pools. For example, the process of photosynthesis transfers carbon dioxide from the atmosphere to plant biomass, and decaying plant and animal matter transfers carbon into soils. During photosynthesis, plants convert carbon dioxide and water into sugar in the presence of sunlight. Some of the sugars are used as building blocks to form plant biomass, such as cellulose, lignin, bark, and leaves. Through this process, carbon moves from the atmosphere and is stored in plant cells. Building and maintaining these complex structures requires energy, which the plants create by converting some of the sugars made during photosynthesis into ATP (adenosine triphosphate). ATP is created through the process of respiration, which releases some carbon dioxide back into the atmosphere.
13	Now we are going to look at carbon in different pools over time. For example, one pool is the carbon stored in growing trees. Another is the carbon stored in short-term wood products, such as paper. This slide acquaints you with the graph that contains data from different carbon pools. The *x*-axis shows the year, over a 160-year period. The *y*-axis shows the amount of carbon in the pool, in metric tons. The carbon not in the pool is in the atmosphere, so students could imagine that the goal is to maximize the carbon in these various pools over time in order to keep that carbon out of the atmosphere.
14	In this slide, we can see metric tons of carbon stored per hectare in a forest over a span of 165 years. This pool, **Live Trees**, includes carbon stored in roots, leaves, and trunks of live trees. Notice that this pool grows slowly over time. In 2000, no forest existed in the area described by the graph. By 2045, a substantial forest existed with about 160 metric tons of carbon stored in the trees per hectare. In 2045, the forest is harvested, so the carbon stored in this pool goes back to zero. Then, new trees are planted which begin to grow. By 2090, the forest has again grown to the point that about 160 metric tons of carbon are stored in the trees. At that point, the forest is cut down again, taking this carbon pool back to zero again.
15	In this slide, the **Dead Wood** carbon pool, the carbon is stored in litter and dead portions of trees. Dead wood is almost too small to be seen in the graph. It is accumulating all the time as leaves or branches fall off the tree. However, those fallen leaves or branches are constantly decomposing, which keeps this pool relatively small and sends carbon back to the atmosphere. However, when the trees are harvested (in 2045, 2090, and 2135), parts of the trees are left behind to decompose in the forest. This pool increases in each of those years because of the dead wood created during harvesting. Over time this wood decomposes, and the carbon stored in those dead pieces of wood is transferred into the atmosphere as carbon dioxide.

16	Two of the carbon pools refer to wood products: **Short-lived Products** and **Long-lived Products**. Here we see that short-lived wood products, such as paper, decompose relatively quickly. As these products decompose, the carbon stored in them goes into the atmosphere or soil. Notice that the shape of this graph looks similar to that of the **Dead Wood** pool. In both cases, there is a jump when the wood is harvested (as some of that wood becomes paper or other short-lived products), and then the pool decomposes over the next few decades.
17	Long-lived wood products, such as lumber, can remain intact for several decades. In this graph, when the first harvest is made in 2045, the pool jumps from 0 to about 60 metric tons of carbon per hectare. This carbon is still being stored when the lumber is used, for example, in construction. In 2090, a second harvest is made, adding another 60 metric tons per hectare. Since the lumber from the original harvest in 2045 is still in use, the 60 tons from this second cut are added to the first, bringing the pool up to 120 metric tons per hectare. In 2125, this pool drops back down to 60 metric tons per hectare. This is because the average lifetime for lumber in a building is about 80 years. The wood from the first cut in 2045 is assumed to have decomposed or been burned by 2125. The pool then jumps up to 120 metric tons per hectare again in 2135, when the third harvest occurs.
18	Since making concrete releases a lot of carbon dioxide, some carbon emissions are avoided when wood is used instead of concrete. This **Carbon Saved** pool shows the carbon that would have been converted from fossil fuels to atmospheric carbon (e.g., carbon dioxide) if concrete were used instead of wood. In other words, these numbers illustrate how much less carbon would be emitted using wood rather than concrete. Notice that each time wood is harvested and used instead of a carbon-intensive material like concrete, this pool goes up by 160 metric tons per hectare. So, at 2045, it jumps from 0 to 160 tons; at 2090, it jumps from 160 to 320 tons; and at 2135, it jumps from 320 to 480 metric tons. Some fossil fuel emissions are associated with wood production as well. Using waste wood as a fuel source (instead of fossil fuels) can offset many of these emissions.
19	Now we are ready to start combining the stocks so that we can show them on one graph. To see how this is done, let's look at the data for a few specific years. The first graph shows the carbon stocks at the year 2020. At this point the forest has grown enough to represent about 57 metric tons per hectare stored in live trees. The forest has not been harvested yet, so the other pools have no carbon at this point. You can think of the light blue portion of this graph as the carbon in the air. The second graph (for 2050) shows the pools just after the first cutting of the forest. Notice the absence of a **Live Trees** pool—because the forest has just been cut. There are 35 metric tons per hectare of **Dead Wood**, 10 metric tons/hectare of **Short-lived Products**, and 60 metric tons/hectare of **Long-lived Products**. Notice that these pools are stacked on top of each other

	in the graph. The top of the **Long-lived Products** is at 105 metric tons/hectare (35 + 10 + 60 = 105). In the third graph (2095), we can see the pools just after the second cutting. Again, there is no **Live Trees** pool, since the forest had grown and been cut again since 2050. The difference from the 2050 graph is in the **Long-lived Products** pool. This pool still includes the 60 metric tons/hectare from the first cut and an additional 60 metric tons/hectare from the second cut for a total of 120 metric tons/hectare. In the fourth and fifth graphs (2125 and 2165), note that the forest has grown and each graph shows a relatively large **Live Trees** pool. We'll see a larger difference between the final two graphs when we include carbon saved.
20	Here, we are looking at the same five years, but these graphs include the **Carbon Saved** pool. Since it is a large pool, the pools that we reviewed on the previous slide are compressed. Notice that the same rule applies. We are stacking the pools on top of each other to build these charts. Now, we can see that the **Carbon Saved** pool is largest in 2165 because of the added harvest.
21	Now let's see what the charts look like when we combine the pools in the same way over all the years. First, we start with just the carbon stored in the **Live Trees** pool, growing gradually for 45 years and then being cut. This is similar to the graph we looked at earlier, but the scale on the *y*-axis has changed to make room for the other carbon pools that we will add to this graph. Notice that the five points in time we have already looked at are also on this graph. As we go through the next several slides, we'll see the graph build up to match those five years.
22	Next, we see the **Dead Wood** pool added to the graph. Since we are looking at the total carbon stored at any given time, the **Dead Wood** pool is added to the **Live Trees** pool. When we lay the **Dead Wood** data on top of the **Live Trees** pool data, the combined graph looks like this.
23	Here we can see the original five years displayed on the graph as well.
24	The **Short-lived Products** have been added. At this scale this pool is quite small. You have to look closely here to see the added pool (in yellow).
25	Now the original five years displayed on the graph as well.
26	The addition of the **Long-lived Products** pool is easier to see. Note that from 2045 to 2090, the **Long-lived Products** pool is a constant 60 metric tons. It appears curved only because it is sitting on top of the other carbon pools. As discussed earlier, at 2090 (the second wood harvest) the **Long-lived Products** pool jumps to 120 metric tons. Then at 2125, it drops back

	down to 60 metric tons since the wood from the first harvest has now
27	Here we can see the original five years displayed on the graph as well.
28	And finally, we add the **Carbon Saved** pool representing the carbon emissions avoided by not using more carbon-intensive materials (such as concrete).
29	When we combine all of these pools together like this, we can see a general upward trend in stored carbon over time.