Carbon Cycle Lesson Plan for High School

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High School Math/Science Carbon Cycle Applet lesson plans

These lesson plans are written in a modular format designed to accommodate varying amounts of class time dedicated to the study of climate change. If you have only one to devote to the subject, you will want to start with Day Eight. If you have two days available for study, you should consider using the plans for Days Seven and Eight. If you have eight days available, use days One through Eight in that order, and so on.

While these lesson plans are intended for use in a block-schedule setting of 90-minute class periods, they can easily be adapted to traditional 45-minute class periods by simply running each daily lesson over two class periods.

Below, the main topics covered in each of the eight days' lessons are summarized.

Day One: **Collapse?** The potential for global economic and environmental collapse in our lifetimes is a concern being voiced by more and more scientists and environmental activists in recent years. In his 2011 book <u>World on the Edge</u>, Lester Brown, a globally respected environmentalist and public policy advocate, makes it abundantly clear that the global economy—and human civilization itself—rely on "goods and services" provided free-of-charge by the natural world. Globally, however, these natural services are in steep decline worldwide due to human population growth, climate change and other factors. A detailed examination of Brown's thesis offers an excellent introduction to a comprehensive climate change unit.

Day Two: Solutions! In order to force a hopeful focus on the unit, climate change solutions proposed in Brown's <u>World on the Edge,</u> are explained in detail. High school students learning about these issues for the first time deserve (and appreciate) an unvarnished representation of the dangers we face, but they are poorly served if a "hope" piece is not present from the outset as well.

Day Three: **Climate Change Basics**. Atmospheric composition, the greenhouse effect, carbon sinks, natural global warming feedback loops and long-term climate variability, including the Milankovitch cycles and a detailed look at the Permian mass extinction, make up this science-based lesson.

Day Four: **The History Lesson**. Students beginning to understand the gravity global warming benefit greatly from learning the story of how human awareness of climate change emerged and blossomed over the past 150 years. Particular focus is given to the IPCC, the Denial Industry, the 2009 Copenhagen Conference and the prospects for global carbon emissions agreements.

Day Five: Basic Math Modeling. Students use their Algebra skills to building linear and exponential math models in order to predict future climactic states.

Day Six: Advanced Math Modeling. Students learn that areas under rate curves equate to total accumulated change in the given quantity. They apply this knowledge using the trapezoidal area formula and integrals to calculate areas under rate-of-CO_2-emissions curves. The calculus-based math models created in this fashion offer a final method for predicting future climate states. This lesson requires no previous calculus training and all computations can be performed using the FNINT capabilities of a standard graphing calculator.

Day Seven: Pacala and Socolow's Wedges. In this lesson, students learn about the 2004 work of these two Princeton scientists who created a "menu" of options for

reducing CO2 emissions, each of which eliminates one detailed look at fifteen specific climate change solutions.

Day Eight: The Carbon Cycle Applet. Students use the Carbon Cycle Applet to predicting future climate states by testing assumptions about the carbon emission solutions we will employ in the future.

Carbon Cycle Background Material

Note: If you have not been using the full eight-day's worth of material, start the lesson with the following background information.

Background material:

1) Earth's average global temperature (AGT) has varied widely over its 4.5 billion year history. At times the AGT was so low the planet was a frozen ball of ice from pole to pole. At other times, the AGT was so high there was no year-round ice on the planet at all. It is a remarkable thing that only a few degrees change in AGT can make the difference between an ice age with two miles of ice covering Wisconsin, and an interglacial period like the one we have been enjoying for the past 10,000 years in which Wisconsin is ice free (except in winter). During ice ages like those we've been experiencing every 150,000 years or so in "recent" times, we see AGT fall to about 12 degrees C. During the warm interglacial periods, AGT rises to about 16 degrees. A seemingly minor change of only 4 degrees C in AGT makes a huge difference in global climate.

2) The periodic ice ages and warming trends we've been experiencing for the past couple of million years were all triggered by minor variations in Earth's orbit that occur on a predictable time scale. But very recently, starting about 200 years ago, a new factor has emerged that is having a huge effect on AGT—human CO2 emissions and global deforestation. These human CO2 emissions—which come from burning *C*oal, *O*il and *N*atural *G*as (CONG) has the capacity to raise AGT by up to six degrees C by the year 2100. If that happens we will not recognize Earth's climate any longer—it will be like living on a new planet with much harsher weather, more deserts, less land for growing food, new ranges for many diseases, as much as 50% fewer species, and far less ability to support human civilization.

3) The reason burning CONG (together, known as fossil fuels) impacts AGT is because of carbon. All fossil fuels are energy-rich collections of carbon and hydrogen which release huge amounts of energy when burned. One barrel of oil, for example, contains as much energy as the amount used by 25,000 hours of human labor—and we are currently burning more than 1000 barrels of oil per second. That means oil provides modern civilization with 25 million human-hours worth of energy every second. That means CONG is like buried treasure—but it comes with a price. When we burn fossil fuels, the carbon separates from the hydrogen and binds with oxygen in the atmosphere to produce carbon dioxide—CO2. A little CO2 in the atmosphere is a very good thing—because of the way it traps heat leaving the Earth's surface, the small amounts of CO2 in our atmosphere are responsible for keeping Earth's surface from freezing solid.

4) During the past million years or so, CO2 levels have ranged from about 180 parts per million (PPM) during ice ages to 280 PPM during warm interglacial periods like the one we are in now. In percentage terms, the atmosphere is 78% Nitrogen and 21% oxygen, leaving just 1% left for all of the other gasses. CO2 at 280 PPM is only 28 one thousandths of one percent of the atmosphere—but the atmosphere is so delicately balanced that the tiny change from 180 to 280 PPM is the difference between 12 degrees C (ice age) and 16 degrees C

(present day). Humans—even seven billion of us working together—don't seem big enough to change the balance of the atmosphere, but we have managed to do just that. Since we started burning fossil fuels a few hundred years ago we have raised the CO2 level in the atmosphere from 280 to 392, setting in motion the melting of all things frozen, causing sea levels to begin rising and altering the weather by allowing the atmosphere to hold an additional 5% more water vapor. The increase from 280 to 392 PPM atmospheric CO2 (ACO2) has raised AGT by about 0.5 degrees C so far with another 0.8 degrees C temperature increase on the way. If we continue to burn fossil fuels at the current rate, we will reach 450 PPM ACO2 within 30 years and guarantee a AGT increase of two degrees C compared to "normal.

5) Again, that 2 degree C average global temperature (AGT) increase doesn't sound like much, but scientists believe it would be enough to cause runaway global warming from natural carbon sources. For example, huge amounts of carbon are stored as methane (CH4—the same as natural gas) in the frozen tundra and underwater off the coasts of earth's most northerly land masses. If these methane deposits are released as tundra thaws in the hotter climate humans are creating, AGT could rise far more than two degrees C. The worse global warming gets, the more the tundra will melt, and the more the tundra melts, the more carbon it will release. This in turn leads to still higher AGT and the cycle of hotter-and-hotter continues. Once these natural feedback loops kick in, they are impossible to stop, so it's important that humanity slows its CO2 emissions rate and avoids the 450 PPM ACO2 figure.

6) Human Civilization puts about 9 Gigatons (GT) of carbon into the atmosphere every year. One Gigaton is one billion metric tons, or 2.2 trillion pounds. (By comparison, the weight of all humanity is about one trillion pounds). One Gigaton is also the same as one trillion grams—also known as one Petagram (PG). Remember—one GT is the same as one PG. When those 9 GT of carbon combine with oxygen in the atmosphere, the CO2 produced weigh about 33 GT, so don't get confused when you hear that humans emit 9GT of carbon and 33GT of CO2 per year—they both mean the same thing. For our purposes, it's easier to just talk about carbon emissions for a moment, so we'll be dealing with GT carbon from here on out.   What happens to all that carbon and the CO2 it creates? About 40% of it is absorbed by the oceans, another 30% is taken up by land plants and the remaining 30% enters the atmosphere where it contributes to global warming. We are mighty lucky the oceans and land masses absorb so much of our carbon. These "carbon sinks" keep the atmosphere from absorbing as much CO2 as it would otherwise.

7) Unfortunately, the ocean and land sinks are becoming less able to absorb our excess carbon. Ocean sinks appear to be weakening because warmer ocean water absorbs less CO2 than cold water does, and land sinks may be declining due to the growth of the earth's deserts. IN both cases, the worse global warming gets, the less effective our carbon sinks seem to work. If human carbon emissions continue at the current rate, these natural carbon sinks could continue declining, which would allow more human carbon emissions to collect in the atmosphere, further raising AGT and leading to another natural feedback loop in which higher AGT leads to still higher AGT. Again, scientists believe 450 PPM ACO2 is a cutoff point beyond which these feedback loops become unstoppable.

8) Because of population growth and increases in the standards of living for many

of the world's poor people, the 9 GT of Carbon humans now emit annually is expected to rise to 16 GT C per year by 2060. However, we know that by 2060 we know we must reduce global carbon emissions to 4 GT per year—the amount our natural sinks can absorb. This means we need to cut 12 GT C (16 minus 4) from our global carbon diet in the next 40 years or so to avoid runaway global warming from natural sources and the destruction of our natural sinks. There is no single, enormous change we can make would reduce our carbon emissions by 12 GT per year. But many smaller strategies exist that would cut one GT C per year. Two scientists from Princeton University, Stephen Pacala and Robert Socolow, proposed fifteen strategies back in 2004 each of which would cut one GT of carbon from the annual global emissions total. The triangle-shaped pieces removed from the total carbon budget resemble wedges, which is why we call these fifteen strategies Pacala and Socolow's "wedges". The following website explains each of the wedges: http://cmi.princeton.edu/wedges/ then choose "introduction." (Take students to this website or distribute a handout based on the information handout located there and discuss each of the wedges in order to familiarize students with the concepts involved.)

This marks the end of the background information. Students should now be able to follow the directions below for the following activities.

1) Explain to students that, "the race is on. In Lane One, it's humanity's ever-accelerating annual carbon dioxide emissions. In Lane Two, we have nature's decreasing ability to absorb the CO2 we release. And in lane three, we have the natural feedback loops getting ever-closer to kicking in. The current amount of carbon dioxide in earth's atmosphere (atmospheric CO2 or ACO2) is causing the planet's average global temperature (AGT) to increase. If ACO2 levels rise much beyond the current 395 parts per million (PPM) value, natural stores of carbon long frozen safely away could be released, adding enormous new quantities of ACO2 and driving AGT far higher than the earth has seen for the past 55 million years. This would spell disaster for the global economy, human civilization and millions of species. The natural sources of carbon and other natural global warming feedback loops simply must not be allowed to "kick in." If they do, we will no longer be able to exert any control over the increase in ACO2.

Here's the good news: At the moment we have two things going for us in this great race—first, we can control how much CO2 we release every year from burning fossil fuels. It is definitely within our power to reduce our CO2 emissions. Second, nature is currently still absorbing some of the CO2 we produce—about 4GT gigatons (GT) worth of Carbon (C) every year, in fact. The bad news is Humans are currently producing about 9 of carbon (C) every year by burning fossil fuels and altering land use patterns. (Recall—one GT is also known as one Petagram, or PG). Because of population growth and increases in the standards of living for many of the world's poor people, that value is expected to rise to 16 GT C per year by 2060. However, we know that we can't allow that increase to occur—if we do, the natural feedback loops will certainly kick in."

2) Go to http://cmi.princeton.edu/wedges/ then choose "introduction." Post a sketch of the annual CO2 emissions rate graph from 2000 to 2060, highlighting the triangle with vertices at (2010, 8GT/y), (2060, 16GT/y) and (2060, 4GT/y). Use the graph to illuminate the following explanation:

"Therefore, by 2060 we know we must reduce global carbon emissions from the projected 16 GT/year all the way down to 4 GT per year—the amount our natural sinks can absorb. This means we need to cut 12 GT C from our annual global carbon diet in the next 40 years or so to avoid runaway global warming from natural sources. There is no single change we can make that would reduce our carbon emissions by 12 GT per year. But many strategies exist that would each cut *one* GT C per year. For example, if we simply increased fuel efficiency on the world's auto fleet to 60 MPG average, we would cut one of the 12 GT of annual CO2 emissions we need to eliminate."

3) Sketch a one-GT wedge onto the graph. Label it "Savings from increased auto efficiency." Continue with the explanation:

"Two scientists from Princeton University, Stephen Pacala and Robert Socolow, proposed fifteen strategies back in 2004 each of which would cut one GT of carbon from the annual global emissions total. The triangle-shaped pieces removed from the total carbon budget resemble wedges, which is why we call these fifteen strategies Pacala and Socolow's "wedges".

The following website explains each of the wedges: http://cmi.princeton.edu/wedges/. Take students to this website or distribute a handout based on the information handout located there and briefly discuss each of the wedges in order to familiarize students with

the concepts involved.

4) Break the students up into five groups. The groups:

    A) Efficiency and Conversion strategies; (Wedges 1-4)
    B) Carbon Capture and Storage strategies: (Wedges 5-7)
    C) Coal Replacement strategies: (Wedges 8-9)
    D) Renewable Energy strategies: (Wedges 10-12)
    E) Biostorage Strategies. (Wedges 13-15)

Each group will be assigned from two to four wedges and asked to produce the following to share with the rest of the class:

1) A poster explaining your category and showing the wedges contained in your category. This poster must contain a short descriptive title of five to ten words in length that paraphrase or re-define your category, a short synopsis of the wedges you are assigned and a graphic organizer that helps students from other groups visualize the category and wedges through words and images.

2) A poster for each wedge employing words and images that helps students from other groups understand the concept of the wedge.

3) Your answer to the question—if you had to choose one of these wedges to abandon, which one would it be and why?

After each group has completed their posters and decided which wedge to abandon, the groups present their posters to the whole group.

Next, class votes on which two of the five abandoned wedges to keep. The other three are then deemed the three least realistic wedges and the other 12 that "make the cut" are the most promising of the CO2 emissions reductions strategies.

(An alternate lesson plan employing the wedges can be found under the "The Wedges Game" tab on the CMI website).

Day 8. The Carbon Cycle Applet Project:
Pacala and Socolow's Wedges and the quest for a below-450 solution.
STUDENT ACTIVITY

In this activity it will be your job to create a plan for solving global warming. You will select twelve of Pacala and Socolow's wedges, decide what year each wedge will be implemented, then enter your solution plan into the Carbon Cycle Applet and see if your plan has managed to keep ACO2 levels below 450 PPM.

Directions:

1) The plan you create needs to include 12 of the 15 wedges proposed by Pacala and Socolow. If humanity employs 12 wedges by 2040 we will have reduced our global annual carbon emissions from the projected 16 GT per year to 4 GT per year—the amount natural sinks and sources can absorb for us without allowing more to build up in the atmosphere).

2) For each wedge you choose, explain why you think it is realistic that the wedge could be implemented and describe how the wedge will reduce global carbon emissions by 1 GT—in other words, what mechanism's are at work that lead to the carbon reduction from each wedge you choose?

3) For each wedge you choose, you must state when it will be placed into action. The only available years to choose are 2020 and 2040.

4) After your have created your plan, run the Carbon Cycle Applet and record the following:

   A) The fossil fuel data you input for 2020, 2040, 2060, 2080 and 2100;

   B) Maximum CO2 PPM reached during the projection run;

   C) Ending value of CO2 reached by the projection run.

   D) A sketch of the shape of the projection curve, labeling max point and end point.

5) Two important reminders about using the Carbon Cycle Applet:

   A) Set the land use, land sinks and ocean sinks lines to a horizontal position before you start your work

   B) *DO NOT PRESS RESET*…doing so would undo your horizontal line   work.

Running the carbon Cycle Applet

http://carboncycle.aos.wisc.edu/

The Carbon Cycle Applet contains four input settings:
Fossil Fuels,   Land Use Changes,   Ocean Sinks   and   Land Sinks.

To begin the process of inputting your data you need to do the following:

A) Set the Ocean Sinks, Land Sinks and Land Use graphs so that they become horizontal lines. Do this by sliding the open circles up or down on the green in for each of the inputs. We do this not because we actually expect these factors to remain unchanged into the future, but in order to isolate a single variable—Fossil Fuels—in our model. (You may have a hard getting them horizontal but do the best you can for this first run. For instance set Land Use to around +.8 at each time step. Ocean Uptake to -2.6, and Land Update to about -3.5)

B) The fossil fuel graph is pre-set with the following carbon emission prediction values from the IPCC (Intergovernmental Panel on Climate Change) for the following future years:

(2020,   10.5 GT carbon per year)

(2040,   15.0 GT C/y)

(2060,   19.5 GT C/y)

(2080,   24.0 GT C/y)

(2100,   28.6 GT C/y)

The IPCC figures predict these enormous increases in carbon emissions because of projected population growth and the expected increase in people's standards of living into the future.

The shaded light blue area is the range the IPCC considers as potentially possible. The realistic expectation of the IPCC is the solid green line with open circles. Each open circle is slide able by you to set value your

Wedge Adjustments in 2020

Your job now is to reduce these carbon emissions values based on the **wedges you propose putting into place in 2020 and 2040**. For each wedge you put into place in 2020, you need to decrease the 2020, 2040, 2060, 2080 and 2100 carbon emissions values by one GT. For example, if you decided to implement 5 wedges in 2020, your new fossil fuel figures would be:

(2020,   5.5 GT carbon per year)

(2040,   10.0 GT C/y)

(2060,   14.5 GT C/y)

(2080,   19.0 GT C/y)

(2100,   25.3 GT C/y).

Wedge Adjustments in 2040

Next, you must repeat this process to account for the wedges you plan to put into place by 2040. For each wedge you put into place in 2040, you need to decrease the 2040, 2060, 2080 and 2100 carbon emissions values by one GT. For example, if you decided to implement 7 wedges in 2040, your new fossil fuel figures would be:

(2020,   5.5 GT carbon per year)

(2040,   3.0 GT C/y)

(2060,   7.5 GT C/y)

(2080,   12.8 GT C/y)

(2100,   18.3 GT C/y).

Run the Carbon Cycle Projection Simulation 1 (CO2 effect alone)

C) Now that you have Steps A and B above completed you are ready to run the Carbon Cycle Applet to see if the wedges you put into place were enough to keep atmospheric CO2 levels below 450 ppm. When you click on the "**Run Projection**" button, keep an eye on the upper right-hand corner of the picture at the bottom of the screen where you will see the year and the atmospheric CO2 concentration appear. When the projection run is over, you can place your cursor on the green projection line for data on the CO2 value for each year of your projection. Write a brief statement about the results of your experiment including answers to the following questions and sketch the shape of the projection curve, locating the maximum, minimum and final values on your sketch.

   1) What was the highest CO2 reading?

   2) In what year did it occur?

   3) What was the final reading in 2100?

   4) Was the CO2 curve increasing, decreasing or horizontal at the end?

Run the Carbon Cycle Projection Simulation 2 (add effect of land use and ocean)

D) After running the Carbon Cycle Applet using the 12 wedges approach with all the other factors set to a horizontal position, run the Applet again—but this time use all of your background knowledge about the growth and decay of carbon sinks, your understanding of land use changes and everything you have learned about climate change solutions in order to make a more accurate prediction about what you believe the next 90 years have in store.

   Imagine what you believe the appropriate Ocean Sinks levels will be in 2020, 2040, 2060, 2080 and 2100, then write a short statement about why you chose the levels you chose. Do the same for Land Sinks, Land Sources and Fossil Fuel sources. Record the levels you chose for each of these variables then run the Carbon Cycle Applet again and record the results of this second experiment including answers to the four questions above and a sketch of the final projection graph.