Name: ________________________ Date: ___________ Hour: _______

A Poker Chip Model of Global Carbon Pools and Fluxes

Sample student worksheet and discussion questions

1. What is a pool or reservoir?

   A carbon pool or reserve is a place that stores carbon in different forms. For example, the atmosphere is a reserve primarily for carbon dioxide. The fossil fuel pool contains hydrocarbons, such as coal and natural gas. The atmospheric pool contains gases, primarily carbon dioxide.

2. For each pool listed below, list primary form(s) of carbon. If possible, describe the forms of carbon both at the macro (visible) and micro (atomic-molecular) scale. For example, living plants would represent the macroscopic visible scale, which store of their carbon in cellulose molecules inside their cell walls, which represents the atomic-molecular scale.

Global Carbon Pool	Primary forms of carbon
Vegetation	*plants, cellulose*
Soils	*decomposing plants, organic matter*
Fossil fuel reserves	*Coal, crude oil, natural gas (hydrocarbons or molecules with C-C and C-H bonds)*
Atmosphere	*carbon dioxide (CO_2), methane (CH_4)*
Upper ocean and marine life and deep ocean	*bicarbonate (H_2CO_3), calcium carbonate ($CaCO_3$), plankton, organic matter, decomposing plants*
Sedimentary rock	*Limestone, shale, calcium carbonate, ($CaCO_3$)*

Word bank – may use words more than once(optional):

calcium carbonate ($CaCO_3$)   shale   bicarbonate (H_2CO_3)   coal

plankton   methane (CH_4)   natural gas   carbon dioxide (CO_2)

cellulose   crude oil   limestone   organic matter   decomposing plants

plants

3. What is a Gigatonne (Gt)? Global carbon pools and fluxes are huge! They are typically measured in gigatonnes. A gigatonne is one billion metric tons! A metric ton (tonne) is 1000 kilograms or ~2200 pounds (a little more than a ton). For reference, a large bull or a small car might weigh 1000 kg. So a Gt is approximately the mass of a billion large bulls or small cars. The average

mass of a 13 year old is 100 pounds or 45 kilograms. How many 13 year olds are in a tonne?

$\frac{2200\ lbs}{100\ lbs} = 22\ thirteen\ year\ olds$ or $\frac{100\ kg}{45\ kg} = 22.2\ thirteen\ year\ olds$

4. Model the carbon pool sizes: To create a scale model of the amount of carbon stored in each pool, stack poker chips and/or construct paper columns representing the amount of carbon in each location as instructed by your teacher.

Carbon Pool	***Carbon (Gt)***	***Number of poker chips (1 chip = 100 Gt, round to nearest hundred)***	***Number of petri dishes (2 dish = 10,000 Gt, round to nearest ten thousand)***	***Paper height (1 in = 1,000 Gt, round to nearest ¼ inch)***
Vegetation	*530*	*5*	*0*	*0.5*
Soils	*1,950*	*20*	*0*	*2*
Fossil fuel reserves	*1,100*	*11*	*0*	*1*
Atmosphere	*830*	*8*	*0*	*0.75*
Upper ocean and marine life	*900*	*9*	*0*	*1*
Deep ocean	*38,000*	*0*	*4*	*38*
Ocean floor surface sediment	*1,750*	*18*	*0*	*1.75*

5. Discussion questions: Does anything surprise you about the amount of carbon stores in each location? Is the drawing to scale? Where is most of the carbon stored?

Answers will vary. Many will be surprised at how much carbon is in the ocean relative to other pools. It is important to bear in mind how large the ocean is (volume) compared to other pools. Another surprising observation would be that so little carbon is in the atmosphere compared to other pools. But the form of carbon (CO_2 and CH_4) is very important for trapping heat and cycling between organisms and the atmosphere (photosynthesis/respiration).

6. Carbon fluxes. The arrows on the diagram show how carbon moves between carbon pools. These fluxes represent processes that transform and move carbon between pools. For each arrow, discuss what processes (biological and chemical) are causing the flux. You can choose from the options listed

below. Write the process or processes next to each arrow. Put an * next to fluxes that are associated with human activity. For example, human agriculture affects the rate of carbon dioxide release from the soil.

a. Photosynthesis
b. Respiration
c. Combustion
d. Erosion/weathering
e. Diffusion
f. Ocean mixing and sedimentation
g. Volcanism

Flux	***Process(s)***
A	*Photosynthesis*
B	*Respiration, combustion (burning biomass)*
C	*Erosion/weathering*
D	*Diffusion ($CO_2 \rightarrow H_2CO_3$), photosynthesis (smaller)*
E	*Diffusion ($H_2CO_3 \rightarrow CO_2 + H_2O$), respiration (smaller)*
F	*Ocean mixing and sedimentation*
G	*Ocean mixing and sedimentation*
H	*Combustion (fossil fuels)*
I	*Volcanism*

7. Label the carbon flux rates: Flux rate describes the rate at which carbon moves between pools through a variety of natural process and human activities. At the global scale, flux rates are measured in gigatonnes per year (Gt/yr). Write the flux rates provided next to each arrow.

   See handout with flux rates at the end of the teacher guide.

8. Discussion questions: What patterns do you see with the flux rates? Are the numbers between pools balanced? How does the size of the flux compare with the size of the pools? Note: these numbers include fluxes caused by human activity.

   Answers will vary. It is worth noting that flux rates do not correspond to size of the pools, but depend more on the form of carbon and processes that can transform it. For example, CO_2 is rapidly cycled between the processes of respiration/combustion and photosynthesis. Interdependent processes like this lead to fairly balanced flux rates.

9. Dynamic equilibrium and net fluxes:

   A. Some pairs of pools have arrows in both directions connecting them meaning that carbon moves both directions between those pools. If exactly the same amount of carbon moves both directions between two pools, the fluxes have no effect on the size of the pools. There is no net flux. Model the net fluxes by looking first at the fluxes between the atmosphere and the ocean. Use poker chips (100 Gt/yr), pennies or bingo chips (1 Gt/yr) or paper columns to model the two fluxes. What is the net effect of these two fluxes – how do they affect the size of the atmospheric and oceanic pools?

80 – 78.4 = 1.6 Gt represented by two bingo chips

Approximately 1.6 Gt/year of carbon is diffused from the atmosphere into the upper ocean.

B. The net flux is the difference between two opposing fluxes. Calculate and then model with pennies or bingo chips (1 Gt/yr) the net fluxes between pairs of pools.

Flux	***Net flux (Gt)***	***Number of bingo chips (1 chip = 1 Gt, rounded to nearest one)***
A ⇔ B (vegetation ⇔ atmosphere)	*3.2*	*3*
C ⇒ deep ocean	*0.9*	*1*
D ⇔ E (atmosphere ⇔ upper ocean)	*1.6*	*2*
G⇔ F (deep ocean ⇔ deep ocean)	*2*	*2*
H ⇒ atmosphere	*7.8*	*1*
I ⇒ atmosphere	*0.1*	*1*

10. Interpreting Net Fluxes: Look at the net flux rates between vegetation and atmosphere, atmosphere and ocean, upper and deep ocean. Where is the carbon moving? What does the net flux tell you about the balance between carbon transforming processes?

    More carbon is fixed by plants every year than is released through respiration and biomass combustion. Likewise, more CO_2 is diffusing into the ocean than is diffusing back out into the atmosphere.

11. Calculate net flux into atmosphere: Carbon in the atmosphere (CO_2 and CH_4) is particularly important, because it contributes to the greenhouse effect. Increased level of these gases lead to global warming. Look at the fluxes going in and out of the atmosphere every year. How does the number of fluxes into the atmosphere compare to the number leaving? Why is this? Give three examples of human activity associated with the flux from fossil fuels to the atmosphere.

    There are more fluxes into the atmosphere than fluxes leaving. This is because there is no flux from the atmosphere to fossil fuels or to sedimentary rock.

    Examples will vary, but primarily should be focused on fossil fuel burning (vehicles, heating, electricity, etc.).

12. Implications for climate change: How much additional carbon is added to the atmosphere every year? (Hint: This requires subtracting all of the fluxes leaving

the atmosphere (a, d) from those entering (b, e, h, i).) Represent the net flux of carbon into the atmosphere with pennies or bingo chips. Which arrows and what processes are moving carbon into the atmosphere? Which is the biggest net flux into the atmosphere? What is the long-term effect of the net flux of carbon?

Net flux into atmosphere = inputs (b + e + h + i) – outputs (a + d)
= (119.8 + 78.4 + 7.8 + 0.4) – (123 + 80)
= 206.4 – 203
= 3.4 Gt/yr
Therefore the net flux would be represented with 3 bingo chips.

The arrow from fossil fuels is causing the build up of carbon (CO_2 and CH_4) in the atmosphere (arrow h). This is caused by the combustion of fossil fuels for energy. The build up of carbon is trapping heat in the atmosphere and causing climate change.

13. Reducing atmospheric carbon levels: How much would we have to reduce fossil fuel use in order to see atmospheric CO_2 levels fall (assuming all other fluxes stay the same)?

If we reduce fossil fuel use to half (3.9 instead of 7.8 Gt/yr), the net flux of carbon would be 0.8 Gt/yr OUT of the atmosphere. If all of the other fluxes remained the same, the level of carbon in the atmosphere would decline very slowly.

14. Brainstorm and model climate change mitigation strategies: Referring to your diagram, come up with 2 strategies that could reduce the net flux of carbon into the atmosphere. Model one of the strategies on your diagram by either adding or moving bingo chips. Some strategies might require drawing new arrows. Be prepared to explain your model.

Answers will vary. Strategies that reduce combustion of fossil fuels will make the flux from fossil fuels to atmosphere smaller. This can be modeled by moving a bingo chip from the flux back to the fossil fuels pool (leave the carbon in the ground)! Another strategy might be reforestation, which would increase the flux to vegetation (add bingo chip to arrow "a"). Carbon capture and storage technologies might be modeled by drawing a new arrow from atmosphere to sedimentary rocks. Encourage students to be creative but justify answers.

15. Biofuels: Biofuels are fuels for vehicles such as ethanol made from plant material. Use your model to decide whether or not substituting biofuels in for some fossil fuels would help slow the increase in atmospheric carbon dioxide.

This is a specific example for #13 above. Biofuels done right should cycle carbon between the vegetation and the atmosphere. The net effect would be to replace fossil fuels and thus reduce the flux from sedimentary rocks to atmosphere. The *argument could also be made that biofuels made from perennial grass and trees at a large scale could increase the rate of photosynthesis or arrow "a" at the same time.*

Assessment

16. Some people argue that because the flux of carbon dioxide into the atmosphere from fossil fuels is small (7.8 gigatonnes/yr) compared to the influxes from oceans (78.4 gigatonnes) and vegetation (123 gigatonnes/yr), we don't have to worry about our use of fossil fuels. Do you agree with this position? Explain your reasoning.

    Answers will vary. Encourage students to think about the net fluxes from oceans and vegetation into the atmosphere and compare to the net flux from fossil fuels.

Extension questions:

17. Using the yearly flux rate into the atmosphere, calculate how much additional carbon should be in the atmosphere pool in 100 years.

    3.4 GT/yr x 100 yrs = 340 Gt (based on data calculated from question 12).

18. Move the poker chips from one pool to another to represent the movement of carbon into the atmosphere over 100 years.

    3 poker chips should be moved from the sedimentary rocks pool to the atmosphere pool.

19. Model and explain what a "carbon neutral" global system would look like.

    Answers will vary. The only criterion is that the net flux into the atmosphere is 0 or negative. Students could use one or several of the examples in #13 above to do this.