Carbon Cycle and Climate Change

DESCRIPTION

Students create a model from string, toss bean bags, and sort chemical cards to review key processes in the carbon cycle. They then quantitatively model the carbon cycle by playing a board game.

PHENOMENON

How are humans impacting the cycling of carbon on Earth?

GRADE LEVEL 9-12

OBJECTIVES

Students will:

- Use cards to represent the movement of atoms during key processes of the carbon cycle
- Qualitatively and quantitatively model the cycling of carbon between reservoirs within Earth's spheres
- Evaluate the impacts of humans on the carbon cycle and Earth's systems

TIME

TWO 45-MINUTE PERIODS

COMMON CORE STATE STANDARDS

Math

CCSS.MATH.CONTENT.HSN.Q.A.1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

CCSS.MATH.CONTENT.HSN.Q.A.2. Define appropriate quantities for the purpose of descriptive modeling.

English Language Arts

CCSS.ELA-LITERACY.RST.9-10.3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.9-10.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

CCSS.ELA-LITERACY.RST.9-10.7. Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-LITERACY.WHST.9-10.1.E. Provide a concluding statement or section that follows from or supports the argument presented.

NEXT GENERATION SCIENCE STANDARDS

Performance Expectation

HS-ESS2-6 Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models	ESS2.D: Weather and Climate ESS3.C Human Impacts on Earth Systems ESS3.D Global Climate Change	Scale, Proportion, and Quantity Energy and Matter

BACKGROUND

Earth's carbon cycle consists of a series of reservoirs of carbon connected by fluxes, which are exchanges of carbon. Prior to the Industrial Era, carbon fluxes were close to a steady state, as evidenced by the relatively small variations of atmospheric carbon dioxide recorded in ice cores (Ciais et al., 2013). Since the Industrial Era, fossil fuel extraction and combustion has resulted in significant fluxes of fossil carbon to the atmosphere, thus causing a human-induced perturbation in the carbon cycle (Ciais et al., 2013). Increasing atmospheric carbon is resulting in climate change.

PART I

MATERIALS

- Copies of Up in the Air handout [1 per student]
- PowerPoint presentation
- Computer and projector for educator
- Task cards,* in black and white or color, copied double sided onto cardstock and cut [1 class set]
- Reservoir table tents,* in black and white or color, copied onto cardstock, cut, and folded in half [1 class set]
- Small balls of string or yarn [5 for a class set, preferably 5 different colors if possible]
- Meter sticks [at least 5 for a class set]
- Stopwatches [5 for a class set]
- Bean bags, small balls, or wadded-up paper balls [15 for a class set]
- Sorting It Out page* [class set, 1 per every 2 students]
- Chemical cards,* copied onto cardstock and cut [class set, 1 per every 4 students]
- Sandwich-sized zippered plastic bags [class set, 1 for every 2 students]
- *Up in the Air Part 1* instructional video, optional introduction to the lesson for the instructor and students

**See Table 1 for number of copies needed to make a class set for different-sized classes.*

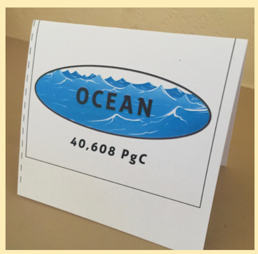

Figure 1. Resevoir table tent, cut and folded to stand up

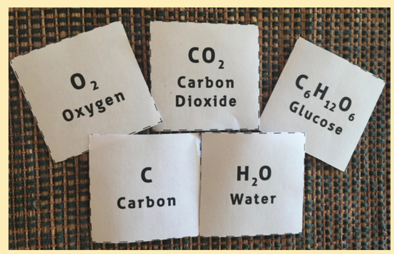

Figure 2. Set of cut chemical cards

PREPARATION

1. If possible, watch the *Up in the Air Part 1* instructional video for an introduction to the lesson. At 1:22, the video can be shown to students to provide an introduction on how to play the game.
2. Set up a computer and projector and display the PowerPoint presentation.
3. Copy the task cards (onto cardstock if available) so that they are double sided, checking that the same reservoir and carbon cycle process line up on the back and front, and cut them in half. Laminate for durability if desired.
4. Copy the reservoir table tents (onto cardstock if available). Cut the reservoir table tents in half on the black dotted line, and then fold them in half on the grey dotted line to enable them to stand up (Figure 1). Laminate for durability if desired.
5. For a class set, copy one set of chemical cards for every four students onto cardstock, and cut on the dotted lines (Figure 2). Place one set into a plastic zippered bag for every two students.
6. If using wadded-up paper balls instead of bean bags or small balls for the Carbon Cycle activity, wad up 15 pieces of scrap paper, and wrap them in masking tape for added weight and durability if desired.

Table 1. Number of copies needed to make a class set for different-sized classes for Part I

		NUMBER OF COPIES NEEDED		
		20 STUDENTS	**30 STUDENTS**	**40 STUDENTS**
TASK CARDS	1 per all students	1	1	1
RESEVOIR TABLE TENTS	1 per all students	1	1	1
SORTING IT OUT PAGE	1 per 2 students	10	15	20
CHEMICAL CARDS	1 per 4 students	5	8	10

PROCEDURES

INTRODUCTION

Introduce the Phenomenon

1. **Slide 2**: during the next two activities, we will be investigating how humans are impacting Earth's carbon cycle.
2. **Slide 3**: carbon appears on Earth in many forms. It can be found alone, such as in diamonds, or combined with other elements to form compounds. Compounds containing carbon include carbon dioxide (CO_2), which is usually a gas in the air, and glucose ($C_6H_{12}O_6$), which plants produce and herbivores eat. Carbon is very important to all living things. It is the primary component of the major molecules in living things, such as carbohydrates, proteins, lipids, and nucleic acids.

THE CARBON CYCLE

Model Carbon Resevoirs and Movement

1. **Slide 4**: scientists have classified the earth into four different spheres: the atmosphere (air), the hydrosphere (water), the geosphere (land), and the biosphere (living systems).
2. **Slide 5**: the spheres contain carbon reservoirs, which are what we call locations where carbon is stored, even for relatively short periods. A reservoir can be an entire sphere, like the atmosphere, or just part of it, like vegetation, which is part of the biosphere.
3. **Slide 6**: today, you will investigate where carbon is stored, the size of the reservoirs, and how carbon moves between them. Next time, you will build a model to describe and quantify carbon cycling, focusing on how much carbon enters the atmosphere.
4. **Slide 7**: to understand the impact of humans on the carbon cycle, we need to know how much carbon there is and where it is stored on Earth. To visualize this, we are going to measure out the relative size of each reservoir using string to make a model.
   a. Every square centimeter (about the size of your pinky finger nail) in the string model you will make represents 1 petagram. A petagram is equal to 10^{15} grams. That is one quadrillion or one thousand billion grams. For scale, the blue whale is the largest, or some would say heaviest, animal ever known to live on Earth. It can get up to almost 100 feet long, which is about as long as two school buses or the smallest Boeing 737 jet airplane. (The jet airplane pictured is the largest of the Boeing 737 line and is 138 ft., which is longer than a blue whale.) A blue whale can weigh about 379,000 pounds or 172 metric tons or 172 million grams. Every petagram is equal to the weight of roughly 6 million blue whales.
      i. In case students ask, the other animals pictured are (from left to right): a carnivorous therapod dinosaur called Carcharodontosaurus saharicus, a large herbivorous sauropod dinosaur called Puertasaurus reuili, a human, a large flying pterosaur (Quetzalcoatlus northropi), an African elephant, and a prehistoric "hornless rhinoceros" (Paraceratherium transouralicum), which was one of the largest terrestrial mammals.
5. **Slide 8**: divide students into five groups. Each group will measure out the relative size of the circumference of one of the carbon reservoirs using string. Give each group a task card, and instruct them look at side #1, which is labeled "Carbon Reservoir." In addition, pass out to each group the corresponding reservoir table tent, at least one meter stick (although the Ocean group may want more than one), and a ball of string. Each group will measure out the length of string indicated on their instruction card and tie the ends together to create a circle.
   Note: string length values on the task cards have been rounded. Therefore, the circle areas for each reservoir will not equal the exact values listed on the cards.
   a. Once all groups have created their reservoir model with string, take a moment to compare and discuss the reservoirs. Ask the Ocean, Soils, and Vegetation groups to show their string models to the rest of the students. Was this what you expected to see?
6. **Slide 9**: how does carbon get into your reservoir? Where does carbon go when it leaves your reservoir?
7. **Slide 10**: to visualize how and where carbon is moving, you will follow instructions on side #2 or "Carbon Cycle" side of your task card.
   Note: side #2 of the task card lists a smaller amount of carbon. This is the amount of carbon that fluxes, or moves, between reservoirs each year. Although this activity qualitatively models the movement of carbon and the flux values are not used explicitly, in Part II, the flux values will be used to quantitatively model the movement of carbon.
8. Within your group, decide who will be in charge of these jobs:
   a. One timer: watch the stopwatch and let everyone know when to throw/walk.
   b. One catcher: collect bean bags coming from other groups.
   c. One or two throwers (or walkers): toss/walk bean bags to their assigned reservoir. The jobs of catcher and thrower may be combined if you do not have enough students in your group.

9. Explain that throwers/walkers will throw (or walk if you prefer) some carbon, represented by one bean bag, to the reservoirs indicated on the task card at the times listed. When the transfer is made, the thrower/walker must say the name of the represented process loudly (photosynthesis, respiration, combustion, decomposition, ocean release or absorption, and fossil fuel formation). The timer must watch the stopwatch and tell the thrower when to transfer the carbon to another reservoir.
10. Ask catchers to stand and hold up their reservoir table tent to show the rest of the groups. Catchers will remain standing so students know to whom to throw/give bean bags.
11. Pass out a stopwatch and three bean bags (or balls or wadded-up paper balls) to each group.
12. When you are ready to start, ask all timers to start their stopwatches at the same time. Throwers will toss (or walk) a bean bag from their reservoir to the receiving reservoir indicated on their task card and say the word for the process being represented loudly. The bean bags are tossed at different times because some processes in the carbon cycle happen quickly, while others happen more slowly, accumulating carbon over time.
13. After two or three minutes, end the activity. Ask students to tell you if they have more or fewer bean bags than when the activity started. [Each group should have roughly the same number of bean bags as when they started.]
14. [Optional discussion, if time permits.] Based on what you know about the carbon cycle, what changes would we need to make to more accurately reflect the carbon cycle of today? [Possible answers: today, carbon is moving out of the Fossil Fuel Reserves quickly as people burn fossil fuels, and carbon is accumulating in the atmosphere. Deforestation in the tropics means that the Vegetation reservoir is shrinking. The Soils reservoir is likely shrinking as well due to changes in land use.]

PROCESSES OF THE CARBON CYCLE

How Does Carbon Move Between Resevoirs?

1. Have students return to their seats (if they moved) and clean up their supplies. Collect the materials. Pass out a handout to each student. Pass out a Sorting It Out page and one set of chemical cards to every two students.
2. **Slide 11**: during the bean bag toss, what words did you hear? Which ones did you hear most often? [answer, click to make circle appear: photosynthesis, respiration, and ocean absorption and release.] Ask the groups that said these processes during the bean bag toss to give a brief description of each process, and expand as needed.
   a. Respiration [Soils or Vegetation]: living things produce energy (adenosine triphosphate, ATP) for their cells by taking in glucose and oxygen and releasing water and carbon dioxide into the atmosphere.
   b. Photosynthesis [Atmosphere]: plants take in carbon dioxide and water and use energy from sunlight (light energy) to make glucose (chemical energy) and oxygen.
   c. Ocean Absorption [Atmosphere]: carbon dioxide dissolves in water and is absorbed by the ocean.
   d. Ocean Release [Ocean]: when there is more carbon dioxide in the water than in the air above it, carbon dioxide is released from the ocean surface.
   Note: gases diffuse between the air and the surface of the ocean. Carbon dioxide in the air can dissolve in water, and cold water can hold more carbon dioxide than warm water. Therefore, as ocean currents move water around the world, cooling water absorbs carbon dioxide from the atmosphere, and warming water releases carbon dioxide into the atmosphere.
3. **Slide 12**: in the processes of the carbon cycle, carbon is moving in the form of molecules. In most cases, the atoms in these molecules are being rearranged to create new molecules. In this activity, you will identify the reactants and products in three of the important processes of the carbon cycle.
4. **Slide 13**: we will start with photosynthesis.
   a. Look through the chemical cards and decide which chemicals you think are involved in photosynthesis. There are two reactants and two products in the reaction. You will not use all of the chemical cards.
   b. Reactants are the substances that enter into a chemical reaction. Which chemicals do you think are used as the reactants in the photosynthesis reaction? Place the reactant cards in the reactant boxes on the Sorting It Out page.
   c. Products are the substances produced in a reaction. Which chemicals do you think are the products in the photosynthesis reaction? Place the product chemical cards in the product boxes on the Sorting It Out page.
5. **Slide 14**: would anyone like to share their answers? What are the reactants and products?
   a. [Click to make the reactants appear.] The reactants are carbon dioxide and water.
   b. [Click to make the products appear.] The products are glucose and oxygen.
   c. Write the answers in the Photosynthesis section of table 1.
6. **Slide 15**: remember, our focus today is on the carbon cycle, and so we are most interested in what happens to the carbon during

the process of photosynthesis. In the Photosynthesis section of Table 1, circle the reactant and product that contain carbon. Which reactant and product contain carbon? [answer, click to make circles appear: carbon dioxide and glucose.]

7. **Slide 16**: which arrow on the diagram in Question 5 represents photosynthesis? [answer: click to make appear, the arrow connected to blank E.]
8. Depending on the time available and the abilities of your students, either give students time to work independently to complete the Respiration and Combustion sections in Table 1 before reviewing the answers, or take them through slides 17-24 as they complete the Respiration and Combustion sections.
9. **Slide 17**: all living organisms, including bacteria, plants, and animals conduct cellular respiration. We will think about respiration next.
   a. Look through the chemical cards and decide which chemicals you think are involved in cellular respiration. There are two reactants and two products in the reaction.
   b. Place the reactant chemical cards in the reactant boxes on the Sorting it Out page.
   c. Place the product chemical cards in the product boxes on the Sorting it Out page.
10. **Slide 18**: would anyone like to share their answers? What are the reactants and products?
    a. [Click to make the reactants appear.] The reactants are glucose and oxygen.
    b. [Click to make the products appear.] The products are carbon dioxide and water.
11. **Slide 19**: again, we are focusing on the carbon cycle today, and so we are most interested in what happens to the carbon during the respiration reaction. In the Respiration section of Table 1, circle the reactant and product that contain carbon. Which reactant and product contain carbon? [answer, click to make circles appear: glucose and carbon dioxide.]
12. **Slide 20**: which arrow on the diagram in Question 5 represents respiration? [answer: click to make appear, the two arrows connected to blank D (from both Vegetation and Soils).]
13. **Slide 21**: combustion is a reaction that results in heat and light, in other words burning. We are going to think about the combustion of coal as an example because approximately 1/3 of the power plants that provide our electricity in the US are powered by coal. Coal is composed mostly of carbon. Coal does contain other elements, such as hydrogen and sulfur, but we will simplify it for our example and just consider the carbon contained in coal during the combustion reaction.
    a. Look through the chemical cards and decide which chemicals you think are involved in the combustion of coal. There are two reactants and one product in the reaction.
    b. Place the reactant chemical cards in the reactant boxes on the Sorting it Out page.
    c. Place the product chemical cards in the product boxes on the Sorting it Out page.
14. **Slide 22**: would anyone like to share their answers? What are the reactants and the product?
    a. [Click to make the reactants appear.] The reactants are carbon and oxygen.
    b. [Click to make the products appear.] The product is carbon dioxide.
    c. Coal, which is mostly carbon, will burn in the presence of oxygen, and the reaction produces carbon dioxide.
15. **Slide 23**: our focus is the carbon cycle, so let's track what happens to the carbon during the combustion of coal reaction. In the Combustion section of Table 1, circle the reactant and product that contain carbon. Which reactant and product contain carbon? [answer, click to make circles appear: carbon and carbon dioxide.]
16. **Slide 24**: which arrow on the diagram in Question 5 represents combustion? [answer: click to make appear, the arrow connected to blank C.]
17. **Slide 25**: gas exchange between the ocean and the atmosphere is not included in Table 1 because there is no chemical reaction involved. Carbon just moves between two locations. Which arrow in the diagram in Question 5 represents ocean carbon release? [answer: click to make appear, the arrow connected to blank A.] Which arrow in the diagram in Question 5 represents ocean carbon absorption? [answer: click to make appear, the arrow connected to blank B.]
18. **Slide 26**: decomposition can happen in many stages, or many different processes, so we will not name the reactants and products. Which arrow on the diagram in Question 5 should be labeled decomposition? [answer: click to make appear, the arrow connected to blank F.]

WRAP UP

1. **Slide 27**: remember that we are considering how humans are impacting the carbon cycle on Earth. Where are humans involved in the carbon cycle and how have we altered it? [Possible answers: humans respire, releasing carbon dioxide into the atmosphere. Humans burn fossil fuels. Cutting down large areas of forests, especially tropical rainforests like the Amazon, reduces the size of the vegetation reservoir.]

PART II

MATERIALS

- Copies of Up in the Air handout (started in Part I)
- PowerPoint presentation
- Computer and projector for educator
- Cup labels [1 for every 2 students]
- Copies of model boards,* in black and white or color, cut, taped together and laminated if desired [class set, 1 for every 2 students]
- Fluxing carbon pieces,* copied onto cardstock and cut [class set, 1 set for every 2 students]
- Game cards,* copied onto cardstock and cut [class set, 1 set for every 2 students]
  - 2 options for game cards, depending on students' background knowledge:
    - Option 1: Process-only game cards (for students who understand carbon cycle processes, such as photosynthesis and respiration)
    - Option 2: Reservoir game cards (for students new to carbon cycle processes)
- Scissors [class set, 1 pair for every 2 students]
- Clear tape [class set, 1 roll for every 2 students]
- Sandwich-sized zippered plastic bags [class set, 2 for every 2 students]
- Small cups (5-oz clear plastic tumblers) [class set, 5 cups for every 2 students]
- *Up in the Air Part 2* instructional video, optional introduction to the game for the instructor and students

* *See Table 2 for number of copies needed to make a class set for different-sized classes.*

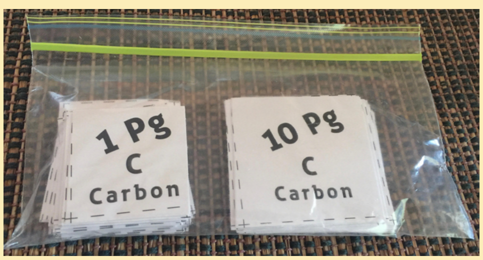

Figure 3. Set of fluxing carbon pieces, cut and bagged

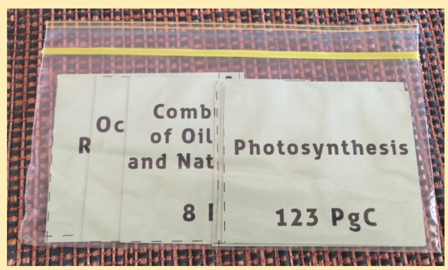

Figure 4. Set of process-only game cards, cut and bagged

Figure 5. Small cup, 5-oz. plastic tumbler

PREPARATION

1. If possible, watch the *Up in the Air Part 2* instructional video for an introduction to the game. At 1:22, the video can be shown to students to provide an introduction on how to play the game.
2. Set up a computer and projector and display the PowerPoint presentation.
3. For every two students, copy one set of cup labels on white copy paper. Do not cut.
4. For a class set, make one model board for every two students. Cut each page along the dotted line, align the pages, and tape them together. Laminate for durability if desired.
5. For a class set, copy one set of fluxing carbon pieces for every two students onto cardstock, and cut on the dotted lines (Figure 3).
6. For a class set, copy one set of game cards, either Option 1 or Option 2 (see below), for every two students onto cardstock, and cut on the dotted lines (Figure 4). If possible, copy the game cards onto a different color cardstock than the fluxing carbon pieces. There are two options for the game cards:
   a. Option 1: Process-only game cards, which only list a carbon cycle process, such as photosynthesis or respiration, and are recommended for students who would be able to determine which two reservoirs to transfer carbon between via the listed process.
   b. Option 2: Reservoir game cards, which list a carbon cycle process and the reservoirs to transfer carbon between, and are recommended for students new to carbon cycle processes.
7. Place each of the following into separate zippered plastic sandwich bags for each group of two students:
   a. 1 set of fluxing carbon pieces of each size: 58 1-PgC pieces and 35 10-PgC pieces
   b. 1 set of game cards [either Option 1 or Option 2 (see 5a. and 5b.)]

Table 2. Number of copies needed to make a class set for different-sized classes for Part II

		NUMBER OF COPIES NEEDED		
		20 STUDENTS	30 STUDENTS	40 STUDENTS
MODEL BOARD	1 per 2 students	10	15	20
FLUXING CARBON PIECES	1 per 2 students	10	15	20
GAME CARDS	1 per 2 students	10	15	20

PROCEDURES

UP IN THE AIR MODEL

Set Up the Model

1. **Slide 28**: last time, you started investigating how humans are impacting the carbon cycle on Earth. You also examined several processes that are part of the carbon cycle. Now, let's put those carbon cycle processes together, and we will come back to our phenomenon question later.
2. **Slide 29**: you will create a quantitative physical model of the carbon cycle. The model is based on published estimates of the amount of carbon moving through Earth, developed from measurements made by scientists. As we discussed last time, carbon cycles through the living and non-living parts of Earth. Remember, the places where carbon is stored, even for relatively short periods, are called reservoirs. Carbon is exchanged in fluxes between reservoirs by biological and geological processes.
3. Divide students into pairs. If there is an odd number of students, create a group of 3 and instruct 2 students to share the role of a single player.
4. To each group, pass out a model board, five small (5-oz) cups, one set of cup labels, a roll of clear tape, a pair of scissors, and a bag containing a set of fluxing carbon pieces. [Optional: place these materials on student tables or desks before class.]
5. **Slide 30**: you and your partner(s) will play the role of all of the carbon on Earth. Remember, you will be working with petagrams of carbon, which is a very large unit. It is equal to one quadrillion grams or one thousand billion grams. It is equivalent to the weight of roughly 6 million blue whales.
6. **Slide 31**: look at the model board. Remember the four different spheres that scientists use to classify the earth: the atmosphere (air), the hydrosphere (water), the geosphere (land), and the biosphere (living systems). We will represent how carbon cycles through these spheres by focusing on five reservoirs, which are located within the spheres of Earth. The Soils reservoir is contained within two spheres. It is classified as being part of the geosphere because it contains non-living components, such as sand, silt, and clay, and is included in the outer layer of Earth. It's also classified in the biosphere, for the purposes of our model, because soil is also comprised of billions of living organisms, such as bacteria and fungi, that decompose organic matter.
7. **Slide 32**: we are going to model one year of carbon cycling on Earth. Most of the carbon in each of the reservoirs will not move during the year that we are modeling. That carbon will just stay in each of the reservoirs. For the purposes of our model, carbon that is not moving during the one-year period that we are modeling is called non-fluxing carbon.
   a. The non-fluxing carbon will be represented by five paper cup labels that show different amounts of carbon (Figure 6).

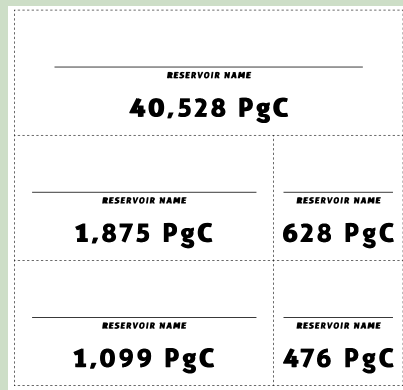

Figure 6. Cup labels

   b. You and your partner(s) must try to determine which of the reservoirs on Earth contain each amount of non-fluxing carbon based on what you remember from Part I of the lesson.
   c. Work together to fill out the reservoir name blanks on the cup labels in pencil. For each amount of non-fluxing carbon listed on the cup labels, choose a reservoir from the reservoir choices box in Section I of the handout. Decide which reservoir name should go on each blank, given what you know about how much carbon is in each reservoir.
   d. Take about two minutes to complete this.
8. **Slide 33**: now look at the table on this slide to check your choices. If you chose incorrectly, erase your answer and correct it at this time.
9. **Slide 34**: cut out the cup labels and tape each of them to a cup. Place the labeled cups onto the

corresponding reservoirs on the model board (Figure 7).

10. **Slide 35**: find the bag of fluxing carbon pieces. Use Table 2 in Section II of the handout to place the correct number of fluxing carbon pieces in every reservoir cup on the model board.
11. It is important to note that each reservoir must contain at least ten 1-PgC pieces, except the Fossil Fuel Reserves reservoir. Note: be sure to stress this and watch that students do it correctly.
12. [Optional] We will place the fluxing carbon in one of the reservoir cups together to demonstrate. We see from Table 3 that the Vegetation reservoir contains 44 PgC. How can we set this up so that it has at least 10 1-PgC pieces? How many of each of the pieces should we use? [answer: 3 10-PgC pieces and 14 1-PgC pieces (Figure 8).]

Play and Analyze the Game

13. Pass out a set of game cards to each group.
14. **Slide 36**: now that all of Earth's carbon is in place, we will play a game. The goal is to move the least carbon to the atmosphere. The player who moves the least carbon to the atmosphere at the end of the game is the winner.
    a. You will first read the instructions on your handout to learn how to play.
    b. You will take turns drawing cards during the game, and once the last card has been drawn, the game is over.
        i. The game cards will list a process, and that will be an indication of how to move the fluxing carbon. For these processes, you can refer back to your answers to Question 5 of the handout to review where carbon starts and moves during the carbon cycle.
            1. For example, if you were to draw a game card that reads "Photosynthesis" (Figure 9), you could refer to Question 5 to remember that the source of carbon is the Atmosphere, and the carbon ends up in the Vegetation.
    c. Each player must leave the game cards that they draw in a stack next to themselves. This is important.
    d. The winner will be determined by who has moved the least carbon to the atmosphere at the end of the game.
    e. Be sure to leave all of your fluxing carbon pieces in place on the game board and your game cards in a stack next to yourself once you have finished the game.
    f. Once you have read the instructions, you can begin.
15. **Slide 37**: display the instructions as students play the game.
16. Instruct students to answer Questions 6-13 on the handout once they have finished the game. Depending on your preferences and students, you can allow students to answer the questions independently and then discuss the answers. If your students need more guidance, you may guide students through answering the questions and discuss the questions as a group.
17. [Optional] The following slides may be used to lead a discussion of Questions 10-12:
    a. **Slide 38**: look at Question 10 to determine how many PgC were added to the atmosphere during the one-year period of the game. [Click to make each number appear.] We ended the game with 207 Pg of fluxing carbon in the atmosphere, which is what you should have calculated in Question 9. We started the game with 201 Pg of fluxing carbon in the atmosphere. That is how much you put in your atmosphere cup at the beginning, using the table on p. 2 in section II. How much was added? [answer: 6 PgC.] Does that sound like a large number? How many

Figure 7. Model board and cups with labels attached

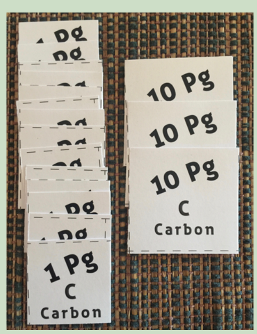

Figure 8. Students will count out 44 PgC of fluxing carbon pieces using 3 10-PgC pieces and 14 1-PgC pieces and then place them in the Vegetation reservoir cup

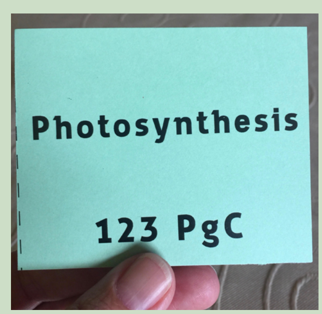

Figure 9. Photosynthesis game card

blue whales would it take to represent 6 PgC? [answer: 36 million blue whales.]

b. **Slide 39**: in answering Question 11, which reservoirs did you choose? Which ones have carbon fluxing to the atmosphere but no carbon fluxing back? [answer: Soils and Fossil Fuel Reserves.] Soils and Fossil Fuel Reserves have arrows pointing to the atmosphere, but there are no arrows pointing back. Oceans and Vegetation both take up some carbon. Which of these, Soils or Fossil Fuel Reserves, is a more recent addition to the carbon cycle? [answer: Fossil Fuel Reserves.] The earth has had soil for approximately 450 million years. Does anyone know when humans started burning fossil fuels as a primary source of energy? [answer: Industrial Revolution, starting around 1760.] The increase in atmospheric carbon dioxide coincides with the start of the Industrial Revolution. Although soils emit carbon dioxide through respiration, photosynthesis and ocean carbon absorption historically offset the emissions from soils.

c. **Slide 40**: would anyone like to volunteer to share your answer to Question 12? Do you think that the flux from Fossil fuel Reserves accounts for the increase in greenhouse gases, such as carbon dioxide, that are affecting Earth's climate? [Answers may vary but should include something related to how the flux from fossil fuels (8 PgC) each year drastically increases the amount of greenhouse gases in the atmosphere, resulting in warming.] As shown in the graph, the increase of atmospheric carbon dioxide began with the Industrial Revolution.

18. [Optional discussion, if time permits.] Look at Question 13. Did you ever remove or add carbon to the modeling board during the game? [answer: no.] Why not? [answer: the amount of carbon on Earth is basically fixed. We get very minute amounts from space, but the amount of carbon on Earth basically stays the same. It just cycles between the living and non-living systems of Earth.] Can carbon be created or destroyed? [answer: no, matter is conserved.]
19. Instruct students to put away the model boards and materials and then collect them. The cup labels are disposable and should be removed and discarded.

WRAP UP

1. **Slide 41**: answer Question 14. How are humans impacting the cycling of carbon on Earth? [answer: increasing carbon dioxide in the atmosphere; could also include deforestation, degradation of soils, ocean acidification, and others.] What do you know about the addition of greenhouse gases and global temperature? [answer: as greenhouse gas concentrations in the atmosphere increase, the average global temperature increases.] What effects are these changes to the carbon cycle having on Earth's systems? [Possible answers include: the increase in atmospheric carbon dioxide will result in increasing temperatures and other impacts to Earth's systems, such as extreme weather events driven by rising sea temperatures, increased frequency of wildfires, and increased sea levels; deforestation reduces the amount of carbon being removed from the atmosphere through photosynthesis; as the ocean absorbs carbon, it becomes more acidified, making it less efficient at absorbing additional carbon dioxide.]
2. **Slide 42**: this graph shows atmospheric carbon dioxide data from the last 800,000 years, which was constructed based on ice core data. Atmospheric carbon dioxide was higher in 2017 than at any point during the last 800,000 years. Using these same techniques, scientists have found that the last time atmospheric carbon dioxide was as high as current levels was more than 3 million years ago. At that time, the global temperature was 3-5 °F higher, and sea levels were 50-80 feet higher than today (Lindsey, 2018).

EXTENSIONS

1. Critique the model. Let's look together at Questions 15-16 and critique this model.
   a. What parts of the game worked well to represent the cycling of carbon quantitatively from one sphere to another? [Possible answers: placing the cup labels (the non-fluxing carbon) on the reservoir cups to represent the carbon that did not move during the game; moving the fluxing carbon pieces from reservoir to reservoir and having those game pieces represent different amounts of carbon; the values of carbon in each reservoir and flux were based on actual data.]
   b. What parts of the game were not effective at modeling the carbon cycle? [Possible answers: the reservoirs on the board were not scaled to represent either their relative physical sizes or amount of carbon; it was conducted over too short of a timeframe (only one year); there is no key on the game board; the cup labels/non-fluxing carbon and fluxing carbon pieces were not scaled accurately to represent relative amounts of carbon; there are reservoirs missing (animals, rocks and minerals, etc.).]
2. Build your own model. Provide students with the carbon reservoir and flux data below and challenge them to develop their own quantitative model of carbon cycling through the hydrosphere, atmosphere, geosphere, and biosphere.

Reservoirs

- Vegetation = 520 PgC
- Fossil fuel reserves = gas + oil + coal = 1107 PgC
- Ocean = surface ocean + intermediate and deep sea + ocean floor surface sediments + marine biota + dissolved organic carbon = 40,608 PgC
- Soils = 1950 PgC
- Atmosphere = 829 PgC

Fluxes (listed per year, values have been rounded)

- Ocean to atmosphere, ocean-atmosphere gas exchange = 80 PgC/yr
- Atmosphere to ocean, ocean-atmosphere gas exchange = 78 PgC/yr
- Fossil fuel reserves to atmosphere, combustion and cement production = 8 PgC/yr
- Atmosphere to vegetation, photosynthesis = 123 PgC/yr
- Soils + vegetation to atmosphere, total respiration + fire = 119 PgC/yr
    - May provide respiration values* separately
- Soils = 75 PgC/yr
- Vegetation = 44 PgC/yr

*Note on respiration values: Ciais et al. (2013) report the amount of respiration from both vegetation and soil together as 119 PgC/year. For the Up in the Air board game, we divided this number so that fluxes can be made from vegetation and soil separately. Schlesigner and Andrews (2000) reported that an estimated 75 PgC/year is transferred from the soil to the atmosphere through respiration. We calculated that approximately 44 PgC/year is remaining, and we used this value for the vegetation respiration flux.

Carbon Reservoir and Flux Data Sources: Ciais et al. (2013) and Schlesinger and Andrews (2000)

ADDITIONAL RESOURCES

Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao and P. Thornton, 2013: Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. [Accessed online: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter06_FINAL.pdf]

Energy.gov. 2013. Solar energy technology basics. Published 16 Aug. 2013. Web. Accessed 11 Jan. 2020. <https://www.energy.gov/eere/solar/articles/solar-energy-technology-basics>

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Energy.gov. 2019. How do wind turbines work? Web. Accessed 11 Jan. 2020. <https://www.energy.gov/eere/wind/how-do-wind-turbines-work>

Environmental Protection Agency. 2018. Greenhouse gas emissions from a typical passenger vehicle. Published May 10, 2018. Web. Accessed 11 Jan. 2020. <https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle>

Lindsey, R. 2018. Climate Change: Atmospheric Carbon Dioxide. NOAA Climate.gov. Published 1 Aug. 2018. Web. Accessed 9 Dec. 2018. <https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>

Schlesigner, W.H. and J.A. Andrews. 2000. Soil respiration and the global carbon cycle. Biogeochemistry 48:7-20.

Name: ____________________ Date: ____________ Period: ________

Carbon Cycle and Climate Change

MATERIALS

Chemical cards, Sorting It Out page

DIRECTIONS

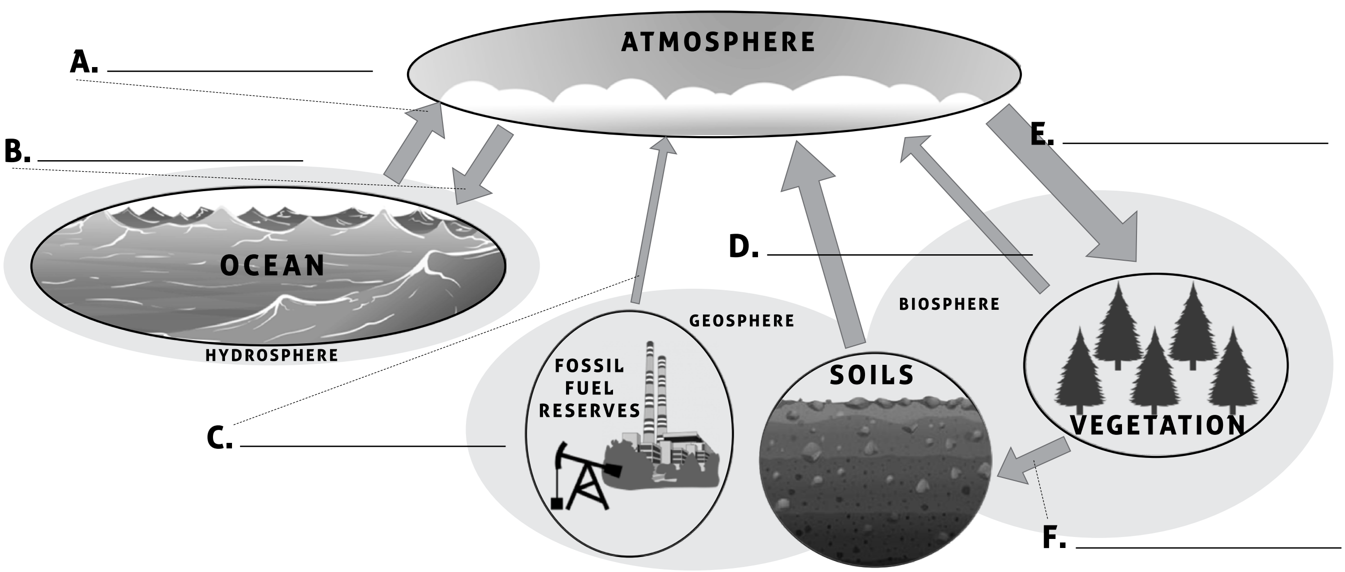
FOR EACH REACTION:

1. Look through the chemical cards and choose the chemicals you think are used as reactants and products. Place the cards in the correct boxes on the Sorting It Out page.
2. Write the chemical formulas for the reactants and products in Table 1 below.
3. Circle the reactant and product that contain carbon.
4. Put the chemical cards back into the stack.

Table 1. Reactants and Products

PHOTOSYNTHESIS		***RESPIRATION***		***COMBUSTION***	
Process used by plants to transform light energy into chemical energy		Process by which organisms use food molecules to produce energy (adenosine triphosphate, ATP) for their cells		Reaction that results in heat and light; in this case, the burning of coal, which is largely composed of carbon	
2 Reactants	***2 Products***	***2 Reactants***	***2 Products***	***2 Reactants***	***1 Product***
________	________	________	________	________	________
________	________	________	________	________	

5. Label the blanks on the diagram below with the name of the process that moves carbon between the reservoirs by the arrows. Blank D is labeling two arrows pointing toward the Atmosphere, one from Soils and the other from Vegetation.



UP IN THE AIR MODEL

I. *Label and Place the Cups*

RESERVOIR CHOICES:
Ocean
Soils
Fossil Fuel Reserves
Atmosphere
Vegetation

Materials: Five small cups, one set of cup labels, tape, scissors, and fluxing carbon pieces

In pencil, write the name of each the reservoirs in the box to the right onto one of each of the cup labels, based on the amount of carbon in the reservoir. Use what you know about how much carbon each of the reservoirs contains to determine which reservoir name to write on each cup label.

Cut out the cup labels and tape each of them to a cup. Place the correctly labeled cups onto the corresponding reservoirs on the model board.

II. *Place Fluxing Carbon Game Pieces*

Use the table below to place the correct number of fluxing carbon pieces in each of the reservoir cups on the model board. Pieces represent fluxing carbon during the 1-year period of the game.

Important: each reservoir must contain at least ten 1 PgC pieces, except the fossil fuel reservoir.

Table 2. Amount of fluxing carbon in each reservoir during the 1-year period of the game

Reservoir	*Approx. Fluxing Carbon (Pg)*
Vegetation	44
Fossil fuel reserves	8
Ocean	80
Soils	75
Atmosphere	201

Data Sources: Ciais et al. (2013), IPCC and Ch. 6 Schlesinger and Andrews (2000)

III. *Play the Game*

Materials: One set of game cards

Follow the instructions below to play the game, and then answer the game questions.

A. Shuffle the game cards and place them face down.

B. The youngest player will go first.

C. Player 1 draws the first card and moves fluxing carbon pieces from one reservoir to another based on the process listed on the card.

    a. Determine which reservoirs to transfer carbon between based on the process listed on the card.

D. Each player will **keep the game cards that they draw in a stack next to themselves**.

E. Take turns drawing cards and moving fluxing carbon pieces until all cards have been used.

F. Once you finish with the game cards, the game is over. **Keep each player's game cards next to them, and leave all of the fluxing carbon pieces in place on the game board**.

Game Questions

6. Look at the game cards that you drew during the game, and **find the ones with the "A" in the top right corner**. These cards indicate carbon that you moved to the atmosphere.

   Determine the amount of fluxing carbon that you **moved to the atmosphere** by adding up the amount of carbon on each of your game cards labeled "A."

   Your fluxing atmospheric carbon: ___________________________ Pg

7. Check with your partner(s). How much fluxing carbon **did your partner move to the atmosphere**?

   Your partner's fluxing atmospheric carbon: ____________________________ Pg

8. Who won? ____
   Name of player who moved the **least** fluxing C to atmosphere

9. Find the total fluxing atmospheric carbon at the end of the game.

   ____________________________ Pg + ____________________________ Pg = _________________________ Pg

Your fluxing atmospheric C	Partner's fluxing atmospheric C	Total fluxing atmospheric C

10. How much fluxing carbon was added to the atmosphere during the 1-year period of the game?

    ____________________________ Pg – ____________________________ Pg = _________________________ Pg

Total fluxing atmospheric C at end of game (question 9)	Total fluxing atmospheric C at start of game (p. 2, sec. II)	Fluxing atmospheric C added during 1-year period of game

    How many blue whales could you use to represent the amount of carbon that is being added to the atmosphere every year? (1 PgC = approximately 6 million blue whales)

11. From which reservoirs is carbon fluxing **to** the atmosphere, but carbon is not fluxing **from** the atmosphere? In other words, on the game board, which reservoirs have an arrow pointing to the atmosphere but none pointing from the atmosphere back to the reservoir?

    Of these reservoirs, which is a more recent source of carbon to the atmosphere?

12. Do you think the flux of carbon into the atmosphere from fossil fuels accounts for the increase in greenhouse gases, such as carbon dioxide, that are affecting Earth's climate? Why or why not?

13. Was carbon ever removed from or added to Earth during the game?

    Can carbon be created or destroyed?

Conclusion

14. How are humans impacting the cycling of carbon on Earth?

    What effects are these changes to the carbon cycle having on Earth's systems?

Extension: Critiquing the Model

15. Which parts of the game were effective at modeling the reservoirs and fluxing of carbon? Why?

16. Which parts of the game were not effective at modeling the reservoirs and fluxing of carbon? Why?

ANSWER KEY

Carbon Cycle and

Climate Change

MATERIALS

Chemical cards, Sorting It Out page

DIRECTIONS

FOR EACH REACTION:

1. *Look through the chemical cards and choose the chemicals you think are used as reactants and products. Place the cards in the correct boxes on the Sorting It Out page.*
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Table 1. Reactants and Products

PHOTOSYNTHESIS		***RESPIRATION***		***COMBUSTION***	
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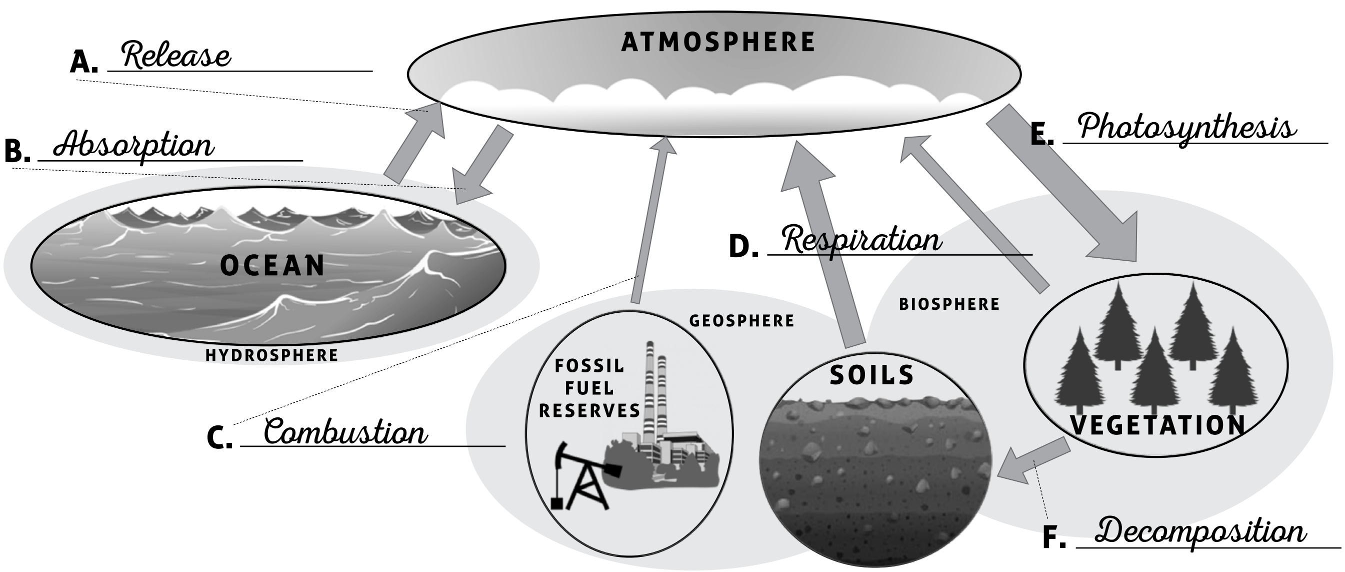
2 Reactants	***2 Products***	***2 Reactants***	***2 Products***	***2 Reactants***	***1 Product***
CO_2	$C_6H_{12}O_6$	$C_6H_{12}O_6$	CO_2	C	CO_2
H_2O	O_2	O_2	H_2O	O_2	

5. Label the blanks on the diagram below with the name of the process that moves carbon between the reservoirs by the arrows. Blank D is labeling two arrows pointing toward the Atmosphere, one from Soils and the other from Vegetation.



UP IN THE AIR MODEL

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Cut out the cup labels and tape each of them to a cup. Place the correctly labeled cups onto the corresponding reservoirs on the model board.

RESERVOIR CHOICES:

Ocean
Soils
Fossil Fuel Reserves
Atmosphere
Vegetation

II. *Place Fluxing Carbon Game Pieces*

Use the table below to place the correct number of fluxing carbon pieces in each of the reservoir cups on the model board. Pieces represent fluxing carbon during the 1-year period of the game.

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Soils	75
Atmosphere	201

Data Sources: Ciais et al. (2013), IPCC and Ch. 6 Schlesinger and Andrews (2000)

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    a. Determine which reservoirs to transfer carbon between based on the process listed on the card.
D. Each player will **keep the game cards that they draw in a stack next to themselves**.
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F. Once you finish with the game cards, the game is over. **Keep each player's game cards next to them, and leave all of the fluxing carbon pieces in place on the game board**.

Game Questions

6. Look at the game cards that you drew during the game, and **find the ones with the "A" in the top right corner**. These cards indicate carbon that you moved to the atmosphere.

   Determine the amount of fluxing carbon that you **moved to the atmosphere** by adding up the amount of carbon on each of your game cards labeled "A."

   Your fluxing atmospheric carbon: Student answers will vary Pg

7. Check with your partner(s). How much fluxing carbon **did your partner move to the atmosphere**?

Your partner's fluxing atmospheric carbon: *Student answers will vary* Pg

8. Who won? *Student answers will vary*
Name of player who moved the **least** fluxing C to atmosphere

9. Find the total fluxing atmospheric carbon at the end of the game.

Student answers will vary Pg + *Student answers will vary* Pg = *207* Pg
Your fluxing atmospheric C | Partner's fluxing atmospheric C | Total fluxing atmospheric C

10. How much fluxing carbon was added to the atmosphere during the 1-year period of the game?

207 Pg – *201* Pg = *6* Pg
Total fluxing atmospheric C at end of game (question 9) | Total fluxing atmospheric C at start of game (p. 2, sec. II) | Fluxing atmospheric C added during 1-year period of game

How many blue whales could you use to represent the amount of carbon that is being added to the atmosphere every year? (1 PgC = approximately 6 million blue whales)

6 PgC (6 million blue whales/PgC) = 36 million blue whales

11. From which reservoirs is carbon fluxing **to** the atmosphere, but carbon is not fluxing **from** the atmosphere? In other words, on the game board, which reservoirs have an arrow pointing to the atmosphere but none pointing from the atmosphere back to the reservoir?

Soils and Fossil Fuel Reserves

Of these reservoirs, which is a more recent source of carbon to the atmosphere?

Fossil Fuel Reserves

12. Do you think the flux of carbon into the atmosphere from fossil fuels accounts for the increase in greenhouse gases, such as carbon dioxide, that are affecting Earth's climate? Why or why not?

Answers may vary but should include something related to how the flux from fossil fuels (8 PgC) each year drastically increases the amount of greenhouse gases in the atmosphere, resulting in warming.

13. Was carbon ever removed from or added to Earth during the game?

No

Can carbon be created or destroyed?

No

Conclusion

14. How are humans impacting the cycling of carbon on Earth?

Humans are increasing the amount of carbon dioxide in the atmosphere. Answers could also include deforestation, degradation of soils, ocean acidification, and others.

What effects are these changes to the carbon cycle having on Earth's systems?

Possible answers include: the increase in atmospheric carbon dioxide will result in increasing temperatures and other impacts to Earth's systems such as extreme weather events driven by rising sea temperatures, increased frequency of wildfires, and increased sea levels; deforestation reduces the amount of carbon being removed from the atmosphere through photosynthesis; as the ocean absorbs carbon, it becomes more acidified making it less efficient at absorbing additional carbon dioxide.

Extension: Critiquing the Model

15. Which parts of the game were effective at modeling the reservoirs and fluxing of carbon? Why?

Possible answers include: placing the cup labels (the non-fluxing carbon) on the reservoir cups to represent the carbon that did not move during the game, moving the fluxing carbon pieces from reservoir to reservoir and having those game pieces represent different amounts of carbon, the values of carbon in each reservoir and flux were based on actual data.

16. Which parts of the game were not effective at modeling the reservoirs and fluxing of carbon? Why?

Possible answers include: the reservoirs on the board were not scaled to represent either their relative physical sizes or amount of carbon, it was conducted over too short of a timeframe (only one year), there is no key on the game board, the cup labels/non-fluxing carbon and fluxing carbon pieces were not scaled accurately to represent relative amounts of carbon, there are reservoirs missing (animals, rocks, minerals, etc.).

#1

CARBON RESERVOIR

Carbon is found in the atmosphere in the form of carbon dioxide (CO_2) gas.

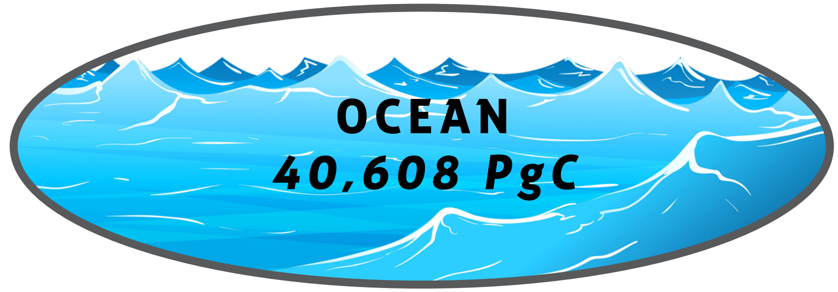
Cut a string 102 cm long, and tie the ends together to create a circle.
Circle area ≅ 829 cm^2

This represents the amount of carbon in the atmosphere.

Scale:
1 cm^2 = 1 Pg Carbon

#1

CARBON RESERVOIR



Carbon is found in the ocean in the forms of dissolved carbon dioxide (CO_2) gas, called carbonic acid, and carbon ions.

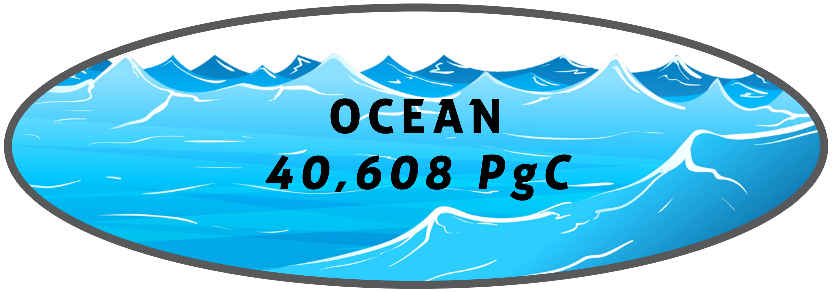
Cut a string 714 cm long, and tie the ends together to create a circle.
Circle area ≅ 40,608 cm^2

This represents the amount of carbon in the ocean.

Scale:
1 cm^2 = 1 Pg Carbon

CARBON CYCLE

#2



Carbon leaves the ocean through gas exchange with the atmosphere. When there is more carbon dioxide (CO_2) in the water than in the air above it, CO^2 is released from the ocean surface. On a much longer time scale, carbon from marine organisms, such as zooplankton and algae, in the ocean is transformed to fossil fuel reserves during the formation of oil.

Thrower 1: Every 15 seconds, give 1 carbon to the Atmosphere and say

Ocean Release

Thrower 2: Every 90 seconds, give 1 carbon to Fossil Fuel Reserves and say

Fossil Fuel Formation

CARBON CYCLE

#2

Carbon leaves the atmosphere through photosynthesis and ocean absorption. In photosynthesis, plants absorb carbon dioxide (CO_2) from the atmosphere and use light energy from the sun to make glucose (chemical energy). The ocean absorbs carbon through gas exchange; CO_2 dissolves in water and is absorbed by the ocean.

Thrower 1: Every 10 seconds, give 1 carbon to Vegetation and say

Photosynthesis

Thrower 2: Every 15 seconds, give 1 carbon to the Ocean and say

Ocean Absorption

1

CARBON RESERVOIR

VEGETATION

Plants take in carbon through photosynthesis and create glucose. Plants and animals use glucose for energy and to build carbohydrates, storing carbon.

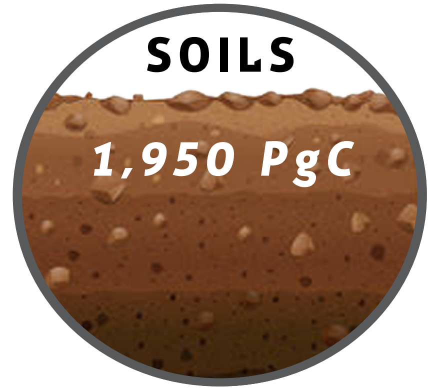
Cut a string 81 cm long, and tie the ends together to create a circle.
Circle area ≅ 520 cm^2

This represents the amount of carbon in vegetation.

Scale:
1 cm^2 = 1 Pg Carbon

1

CARBON RESERVOIR



Soil contains carbon in the form of organisms that live in the soil and decomposing organic matter (bits of dead organisms).

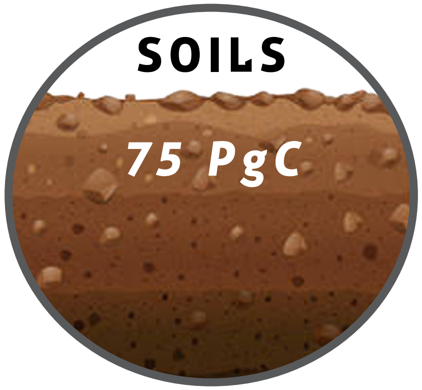
Cut a string 156 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,950 cm^2

This represents the amount of carbon in the soil.

Scale:
1 cm^2 = 1 Pg Carbon

#2

CARBON CYCLE



Carbon leaves the soil through decomposer respiration. Organic matter in the soil is made up of bits of dead organisms. Decomposers break the organic matter down into smaller parts. Decomposers, like all living things, conduct cellular respiration to produce energy for their cells by taking in glucose and oxygen and releasing water and carbon dioxide (CO_2) into the atmosphere.

Thrower 1: Every 15 seconds, give 1 carbon to the Atmosphere and say

Respiration

#2

CARBON CYCLE

VEGETATION

Carbon leaves plants through respiration and decomposition. In cellular respiration, organisms produce energy for their cells (ATP) by taking in glucose (food) and oxygen and releasing water and carbon dioxide (CO_2) into the atmosphere. When living things decompose, they are broken down into small parts, and some carbon remains in the soil as organic matter.

Thrower 1: Every 10 seconds, give 1 carbon to the Atmosphere and say

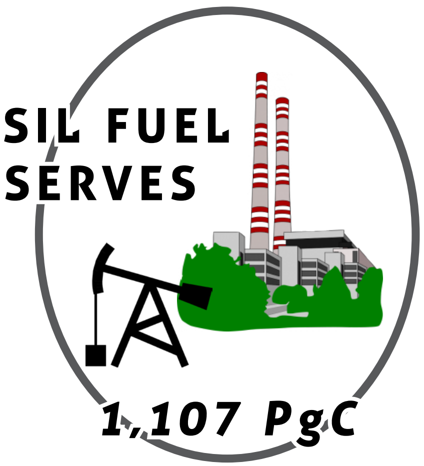
Respiration

Thrower 2: Every 30 seconds, give 1 carbon to the Soil and say

Decomposition

#1

CARBON RESERVOIR



Carbon from ancient plants and animals is stored in the earth as fossil fuels. After the organisms decompose and are buried, heat, pressure, and geologic forces result in the formation of coal and oil.

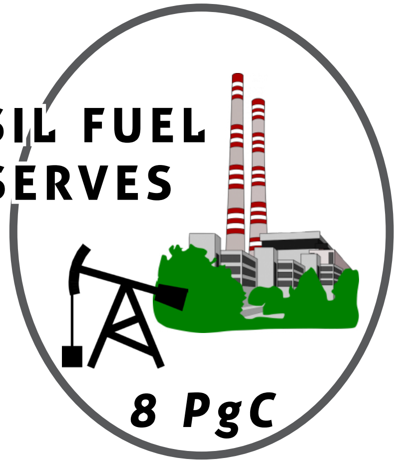
Cut a string 118 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,107 cm^2

This represents the amount of carbon in fossil fuel reserves.

Scale:
1 cm^2 = 1 Pg Carbon

#2

CARBON CYCLE



Carbon leaves fossil fuel reserves when they are extracted and burned. The burning, or combustion, of fossil fuels releases carbon dioxide into the atmosphere. Fossil fuel combustion has increased as humans have developed the technology to extract fossil fuels and use them in generating energy.

Thrower 1: Every 1 minute, give 1 carbon to the Atmosphere and say

Combustion

#1

CARBON RESERVOIR

Carbon is found in the atmosphere in the form of carbon dioxide (CO_2) gas.

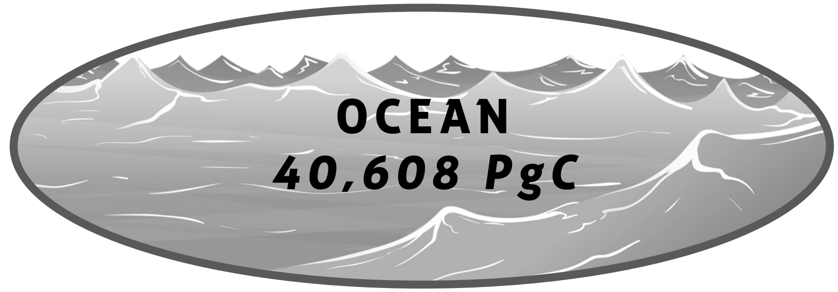
Cut a string 102 cm long, and tie the ends together to create a circle.
Circle area ≅ 829 cm^2

This represents the amount of carbon in the atmosphere.

Scale:
1 cm^2 = 1 Pg Carbon

#1

CARBON RESERVOIR



Carbon is found in the ocean in the forms of dissolved carbon dioxide (CO_2) gas, called carbonic acid, and carbon ions.

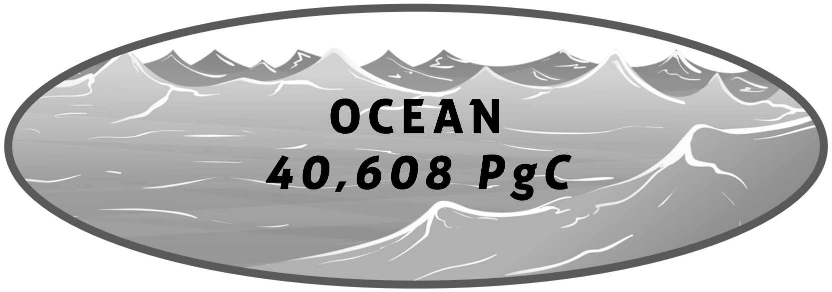
Cut a string 714 cm long, and tie the ends together to create a circle.
Circle area ≅ 40,608 cm^2

This represents the amount of carbon in the ocean.

Scale:
1 cm^2 = 1 Pg Carbon

#2

CARBON CYCLE



Carbon leaves the ocean through gas exchange with the atmosphere. When there is more carbon dioxide (CO_2) in the water than in the air above it, CO^2 is released from the ocean surface. On a much longer time scale, carbon from marine organisms, such as zooplankton and algae, in the ocean is transformed to fossil fuel reserves during the formation of oil.

Thrower 1: Every 15 seconds, give 1 carbon to the Atmosphere and say

Ocean Release

Thrower 2: Every 90 seconds, give 1 carbon to Fossil Fuel Reserves and say

Fossil Fuel Formation

#2

CARBON CYCLE

Carbon leaves the atmosphere through photosynthesis and ocean absorption. In photosynthesis, plants absorb carbon dioxide (CO_2) from the atmosphere and use light energy from the sun to make glucose (chemical energy). The ocean absorbs carbon through gas exchange; CO_2 dissolves in water and is absorbed by the ocean.

Thrower 1: Every 10 seconds, give 1 carbon to Vegetation and say

Photosynthesis

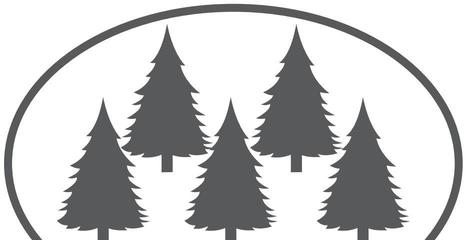
Thrower 2: Every 15 seconds, give 1 carbon to the Ocean and say

Ocean Absorption

#1

CARBON RESERVOIR

VEGETATION



520 PgC

Plants take in carbon through photosynthesis and create glucose. Plants and animals use glucose for energy and to build carbohydrates, storing carbon.

Cut a string 81 cm long, and tie the ends together to create a circle.
Circle area ≅ 520 cm^2

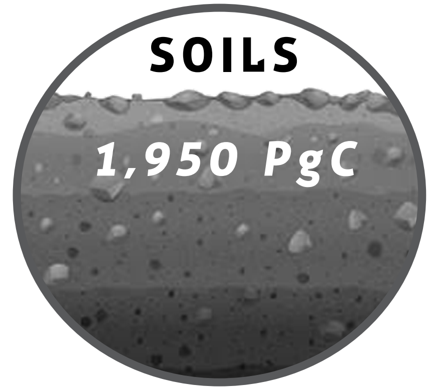
This represents the amount of carbon in vegetation.

Scale:
1 cm^2 = 1 Pg Carbon

#1

CARBON RESERVOIR

SOILS



Soil contains carbon in the form of organisms that live in the soil and decomposing organic matter (bits of dead organisms).

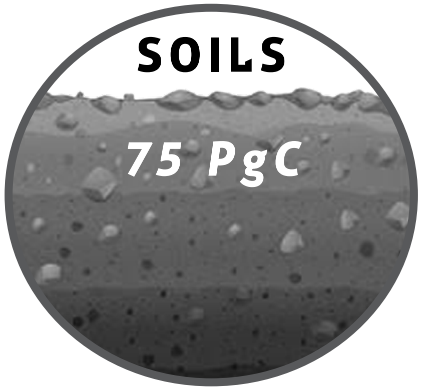
Cut a string 156 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,950 cm^2

This represents the amount of carbon in the soil.

Scale:
1 cm^2 = 1 Pg Carbon

#2

CARBON CYCLE



Carbon leaves the soil through decomposer respiration. Organic matter in the soil is made up of bits of dead organisms. Decomposers break the organic matter down into smaller parts. Decomposers, like all living things, conduct cellular respiration to produce energy for their cells by taking in glucose and oxygen and releasing water and carbon dioxide (CO_2) into the atmosphere.

Thrower 1: Every 15 seconds, give 1 carbon to the Atmosphere and say

Respiration

#2

CARBON CYCLE

VEGETATION

Carbon leaves plants through respiration and decomposition. In cellular respiration, organisms produce energy for their cells (ATP) by taking in glucose (food) and oxygen and releasing water and carbon dioxide (CO_2) into the atmosphere. When living things decompose, they are broken down into small parts, and some carbon remains in the soil as organic matter.

Thrower 1: Every 10 seconds, give 1 carbon to the Atmosphere and say

Respiration

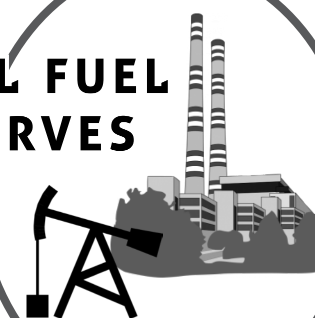
Thrower 2: Every 30 seconds, give 1 carbon to the Soil and say

Decomposition

1

CARBON RESERVOIR

FOSSIL FUEL RESERVES



1,107 PgC

Carbon from ancient plants and animals is stored in the earth as fossil fuels. After the organisms decompose and are buried, heat, pressure, and geologic forces result in the formation of coal and oil.

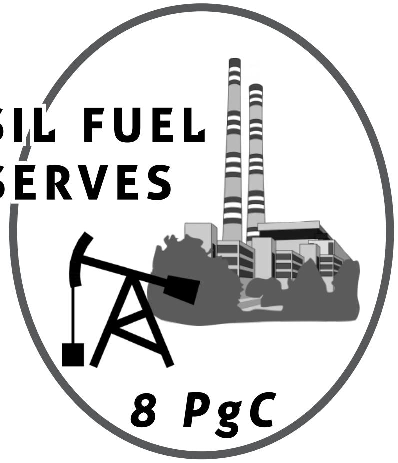
Cut a string 118 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,107 cm^2

This represents the amount of carbon in fossil fuel reserves.

Scale:
1 cm^2 = 1 Pg Carbon

#2

CARBON CYCLE



Carbon leaves fossil fuel reserves when they are extracted and burned. The burning, or combustion, of fossil fuels releases carbon dioxide into the atmosphere. Fossil fuel combustion has increased as humans have developed the technology to extract fossil fuels and use them in generating energy.

Thrower 1: Every 1 minute, give 1 carbon to the Atmosphere and say

Combustion

RESERVOIR TABLE TENTS

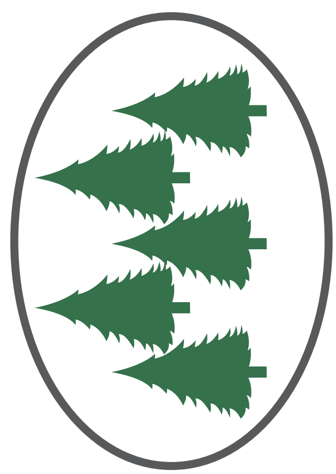
40,608 PgC

829 PgC

RESERVOIR TABLE TENTS

SOILS

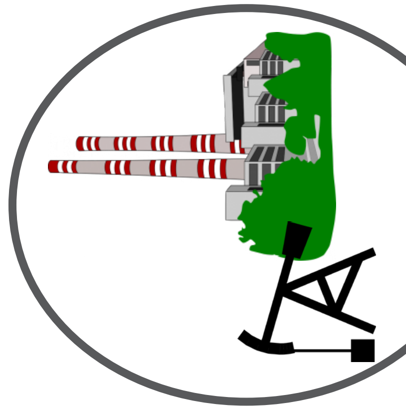
VEGETATION



520 PgC

RESERVOIR TABLE TENTS

FOSSIL FUEL RESERVES



1107 PgC

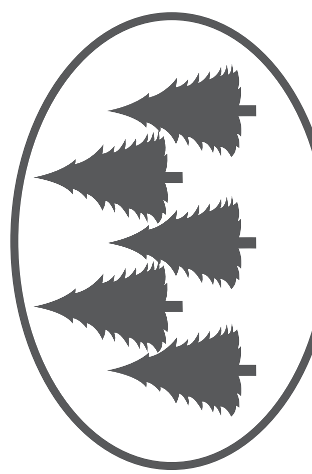
RESERVOIR TABLE TENTS

40,608 PgC

829 PgC

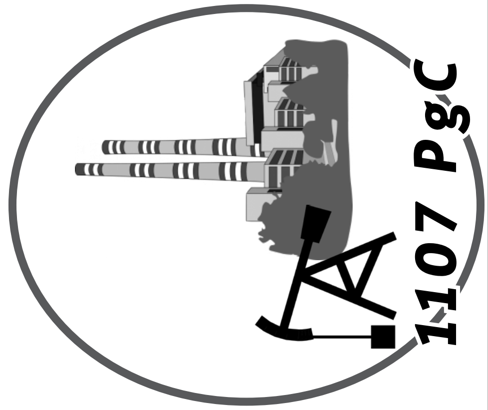
SOILS

VEGETATION



520 PgC

FOSSIL FUEL RESERVES



SORTING IT OUT

DIRECTIONS

Place the chemical cards for each reaction onto the correct box below. Be sure to notice in Table 1 how many reactants and how many products are in each reaction.

REACTANTS	*PRODUCTS*

CHEMICAL CARDS

One copy per every four students, copy onto cardstock and cut. One page makes two sets.

$C_6H_{12}O_6$ **Glucose**	O_2 **Oxygen**	CO_2 **Carbon Dioxide**
H_2O **Water**	C **Carbon**	$C_6H_{12}O_6$ **Glucose**
O_2 **Oxygen**	CO_2 **Carbon Dioxide**	H_2O **Water**
C **Carbon**		

CUP LABELS: NON-FLUXING CARBON

In pencil, write the name of each the reservoirs from the Reservoir Choices Box on p. 2, Section I of the handout onto one of each of the cup labels, based on the amount of carbon in the reservoir. Use what you know about how much carbon each of the reservoirs contains to determine which reservoir name to write on each cup label.

RESERVOIR NAME

40,528 PgC

RESERVOIR NAME

1,875 PgC

RESERVOIR NAME

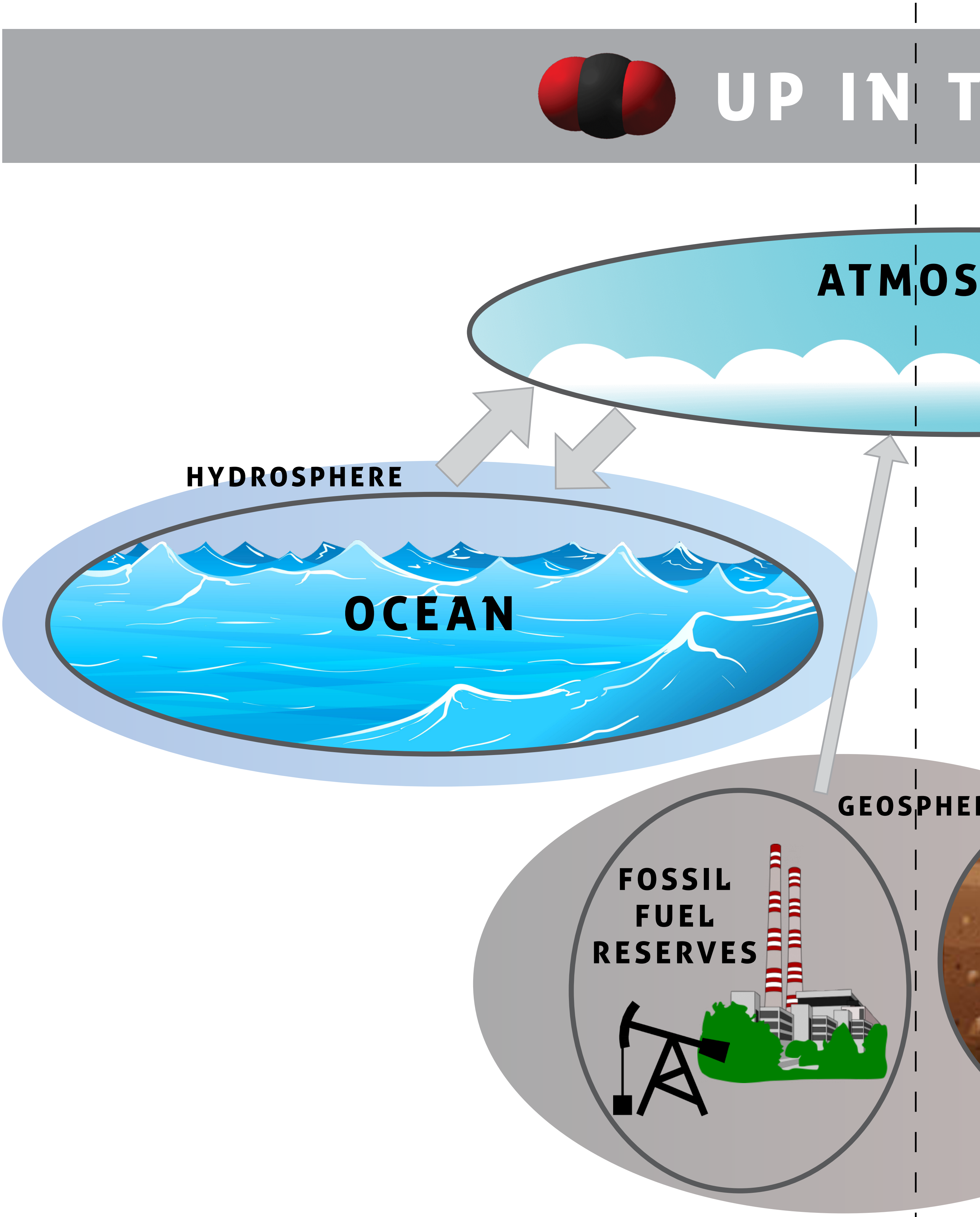
628 PgC

RESERVOIR NAME

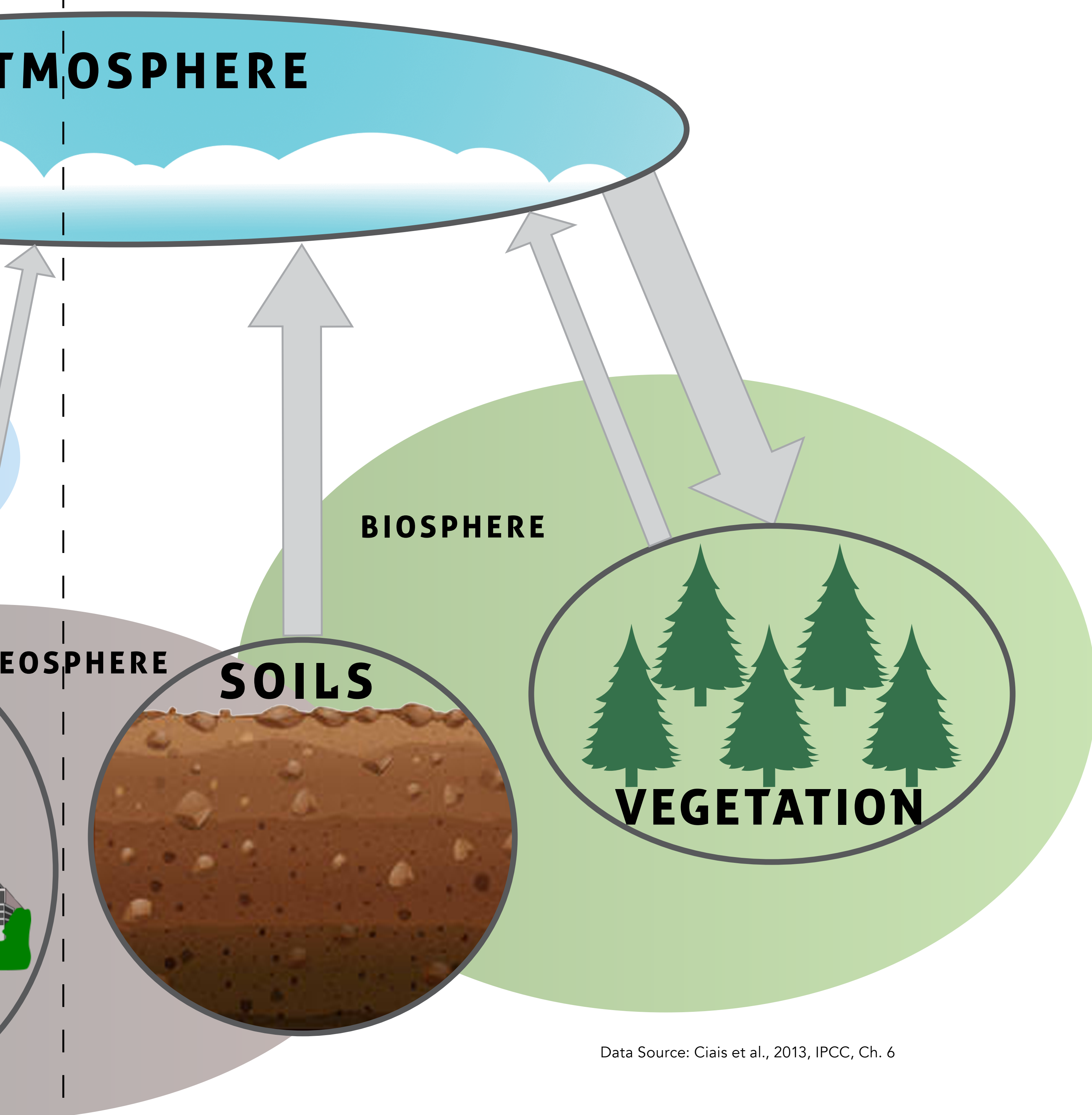
1,099 PgC

RESERVOIR NAME

476 PgC

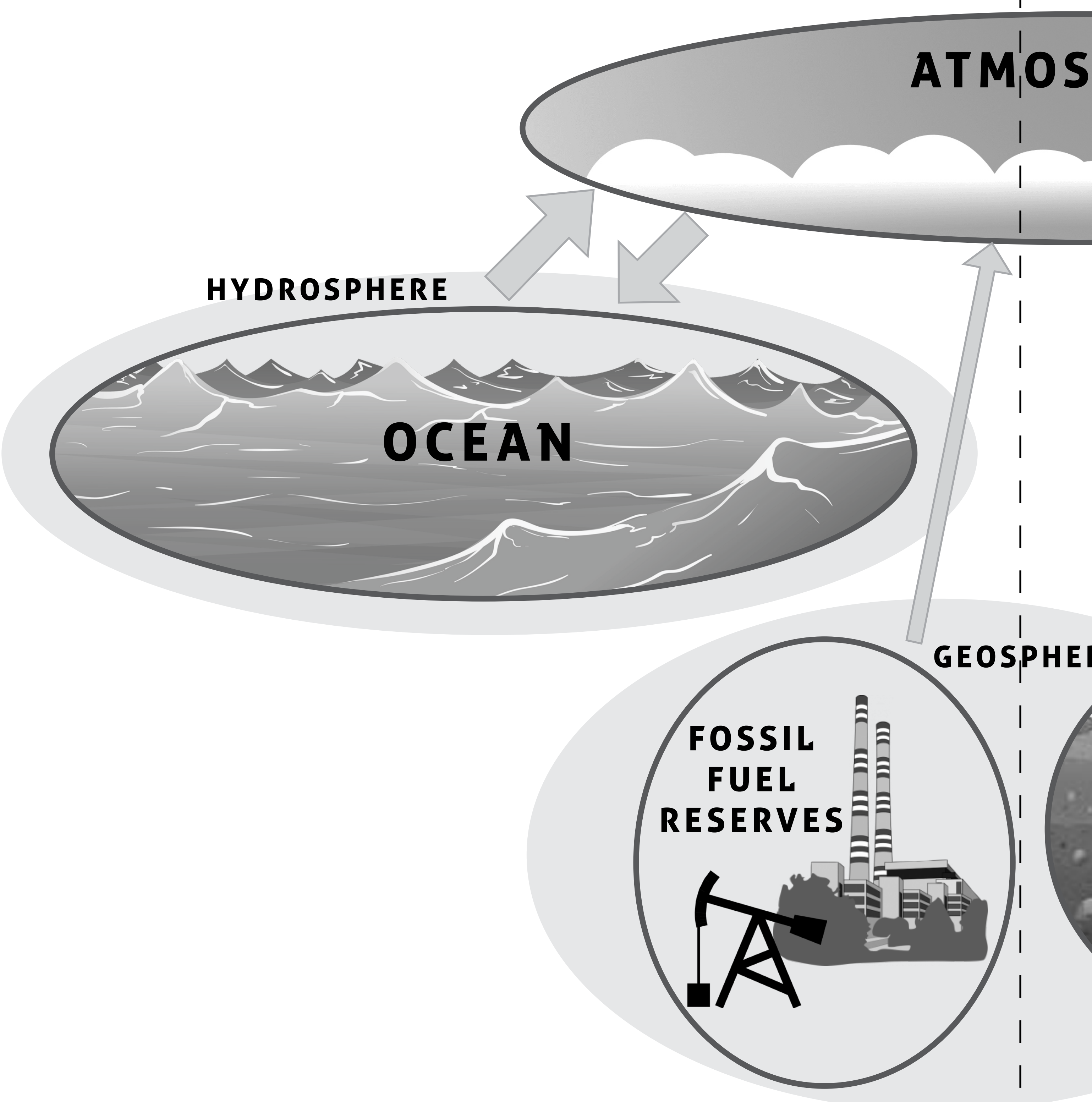

UP IN T
ATMOS
HYDROSPHERE
OCEAN
GEOSPHE
FOSSIL
FUEL
RESERVES

N THE AIR

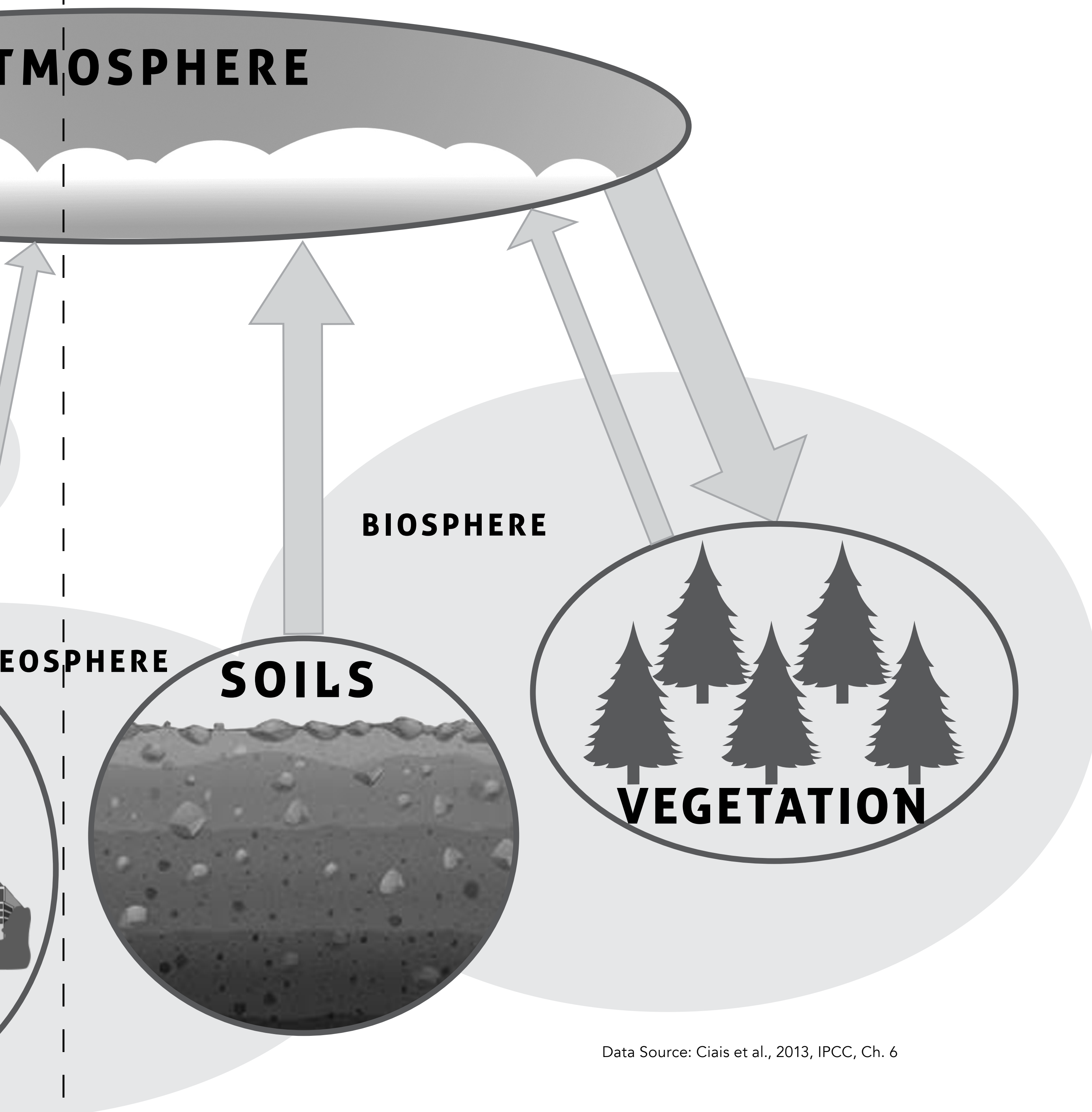


Data Source: Ciais et al., 2013, IPCC, Ch. 6

UP IN T



N THE AIR



Data Source: Ciais et al., 2013, IPCC, Ch. 6

FLUXING CARBON PIECES

One set per every two students, copy onto cardstock and cut.

1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon

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1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon

FLUXING CARBON PIECES

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1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon	1 Pg C Carbon
1 Pg C Carbon	1 Pg C Carbon		

FLUXING CARBON PIECES

One set per every two students, copy onto cardstock and cut.

10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon

FLUXING CARBON PIECES

One set per every two students, copy onto cardstock and cut.

10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon

FLUXING CARBON PIECES

One set per every two students, copy onto cardstock and cut.

10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	10 Pg C Carbon
10 Pg C Carbon	10 Pg C Carbon	

RESERVOIR GAME CARDS

One copy per every two students, copy onto cardstock and cut.

A

Ocean Carbon Release

From Ocean to Atmosphere

80 PgC

Ocean Carbon Absorption

From Atmosphere to Ocean

78 PgC

A

Combustion of Oil, Coal, and Natural Gas

From Fossil Fuel Reserves to Atmosphere

8 PgC

A

Soil Respiration

From Soils to Atmosphere

75 PgC

A

Vegetation Respiration

From Vegetation to Atmosphere

44 PgC

Photosynthesis

From Ocean to Atmosphere

123 PgC

PROCESS ONLY GAME CARDS

One copy per every two students, copy onto cardstock and cut.

A **Ocean Carbon Release** **80 PgC**	**Ocean Carbon Absorption** **78 PgC**
A **Combustion of Oil, Coal, and Natural Gas** **8 PgC**	A **Soil Respiration** **75 PgC**
A **Vegetation Respiration** **44 PgC**	**Photosynthesis** **123 PgC**