CLIMATE CHANGE *and* THE CARBON CYCLE

A Curriculum Unit for 9-12 Grade Students

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CURRICULUM DEVELOPMENT
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CLIMATE CHANGE AND THE CARBON CYCLE

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STANDARDS ALIGNMENT

CLIMATE CHANGE AND THE CARBON CYCLE

A Curriculum Unit for 9-12 Grade Students

Welcome! This unit was designed to introduce 9-12 grade students to climate change, the carbon cycle, and the effects of increasing atmospheric carbon dioxide on Earth's climate. The activities in this guide are appropriate for both formal and informal education settings, and they can be modified to fit the needs of students. All activities are aligned to Common Core State Standards and Next Generation Science Standards.

This curriculum is organized as a 4-day unit, with each activity building on the last. The unit need not be completed in its entirety, however. All of the activities can be conducted individually as well. There are three activities, and one spans two days (or class periods). The Unit Schedule outlines a proposed schedule of activity completion, assuming 45-minute periods. Each activity includes an estimated time for completion.

The materials required for the activities can generally be purchased at a household goods store, and some are items that many educators often have available. There are very few specialized supplies needed. Each activity includes a materials section that lists the items required to complete the activity, with provided resources, such as handouts and PowerPoint files, listed first. When viewing this guide electronically with an internet connection, the links within the materials section will navigate to each of the listed resources.

We hope that you and your students enjoy these activities! Please contact information@asombro.org with questions and feedback.

CLIMATE CHANGE AND THE CARBON CYCLE

Unit Schedule

This unit is designed to be conducted over four days. The unit need not be completed in its entirety, however. The activities can be conducted individually as well.

Day 1 **UP IN THE AIR** ***Carbon Cycle and Climate Change, Part I***	*Day 2* **UP IN THE AIR** ***Carbon Cycle and Climate Change, Part II***
Day 3 **THE INS AND OUTS OF A CLIMATE FEEDBACK LOOP**	*Day 4* **WHAT'S THE PLAN?** ***Climate Change Mitigation***

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.*

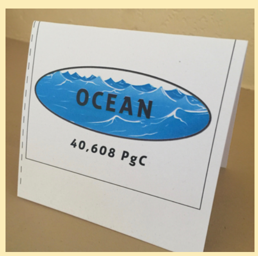


Figure 1. Resevoir table tent, cut and folded to stand up

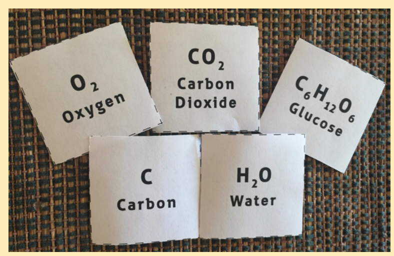


Figure 2. Set of cut chemical cards

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.*

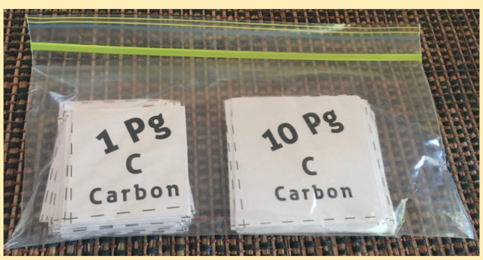


Figure 3. Set of fluxing carbon pieces, cut and bagged

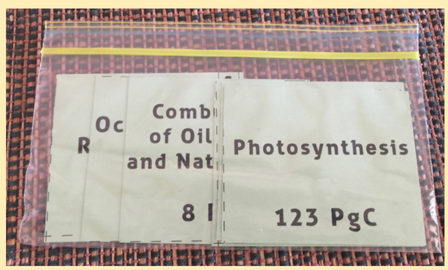


Figure 4. Set of process-only game cards, cut and bagged

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).

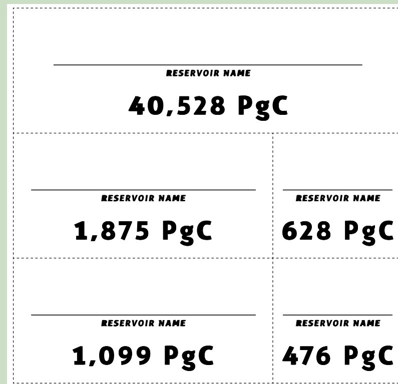


Figure 6. Cup labels

   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

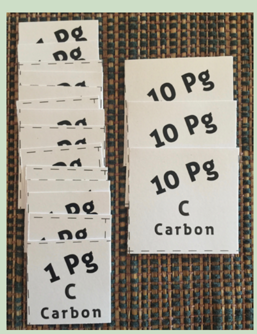


Figure 8. Students will count out 44 PgC of fluxing carbon pieces using 3 10-PgC pieces and 14 1-PgC pieces and then place them in the Vegetation reservoir cup

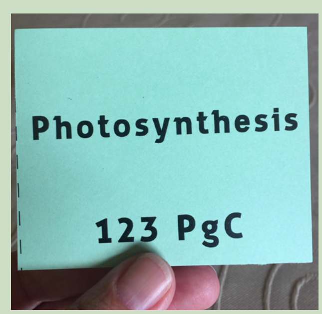


Figure 9. Photosynthesis game card

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>

Energy.gov. 2018. How much power is 1 gigawatt? Published 9 Aug. 2018. Web. Accessed 18 Dec. 2018. <https://www.energy.gov/eere/articles/how-much-power-1-gigawatt>

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 — UP IN THE AIR — Climate Change

MATERIALS

Chemical cards, Sorting It Out page

DIRECTIONS

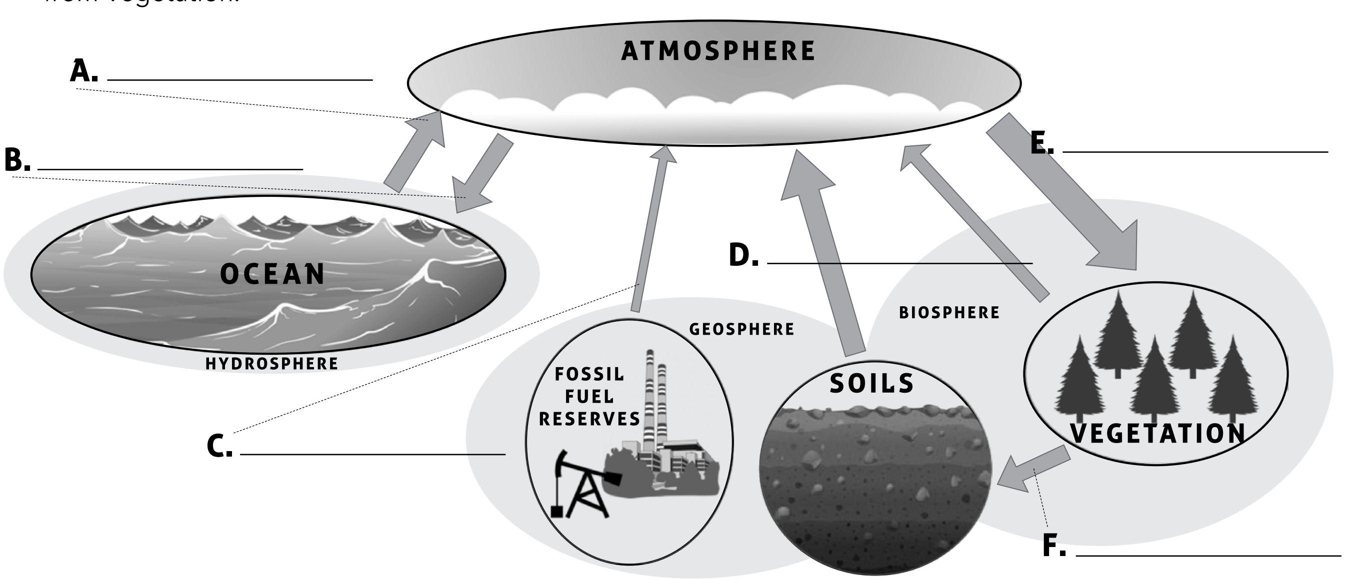
FOR EACH REACTION:

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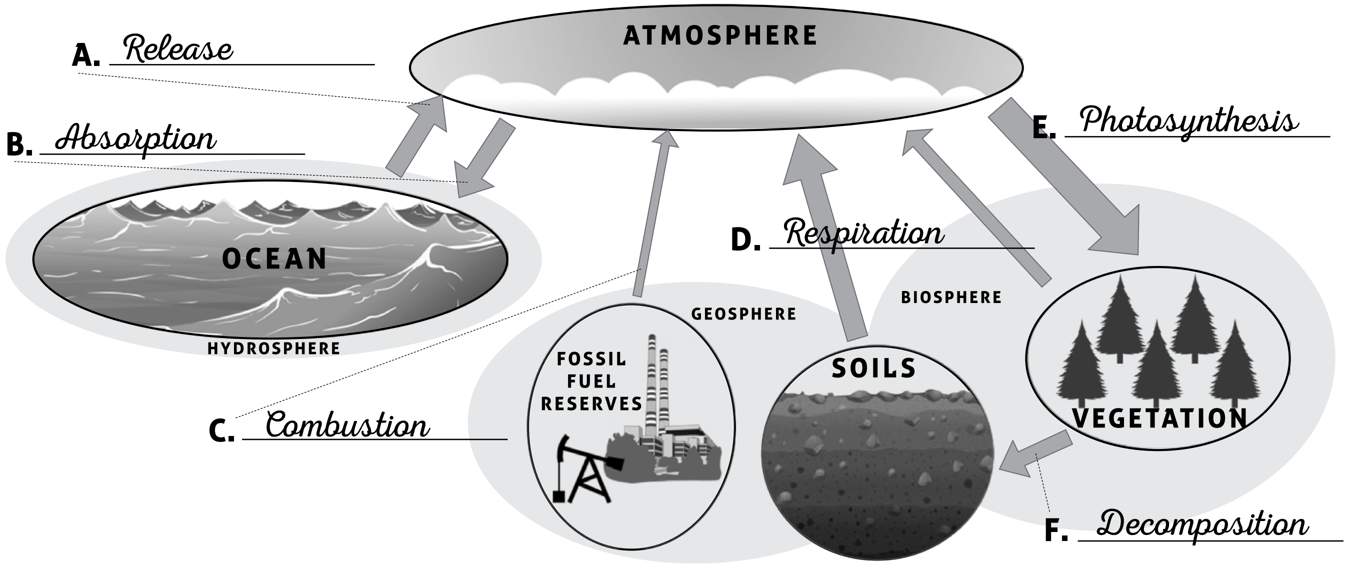
2 Reactants	**2 Products**	**2 Reactants**	**2 Products**	**2 Reactants**	**1 Product**
CO_2	$C_6H_{12}O_6$	$C_6H_{12}O_6$	CO_2	C	CO_2
H_2O	O_2	O_2	H_2O	O_2	

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

I. *Label and Place the Cups*

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.

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.

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)
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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.

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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**.

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: *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.

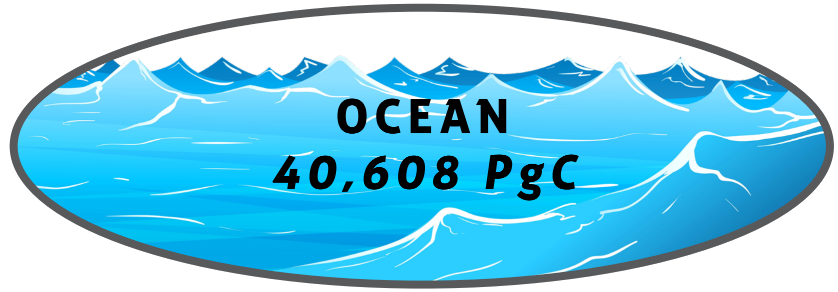
Cut a string 102 cm long, and tie the ends together to create a circle.
Circle area ≅ 829 cm^2

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.

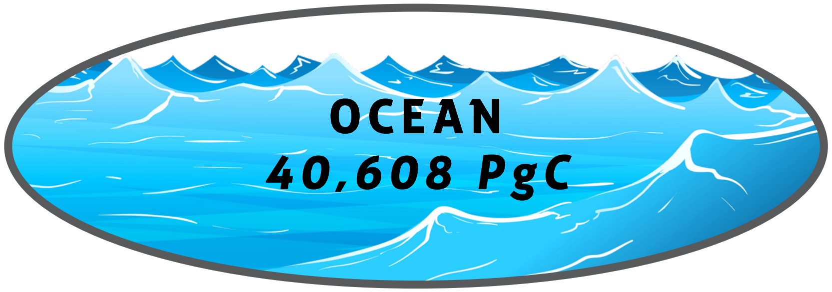
Cut a string 714 cm long, and tie the ends together to create a circle.
Circle area ≅ 40,608 cm^2

This represents the amount of carbon in the ocean.

Scale:
1 cm^2 = 1 Pg Carbon

#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

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

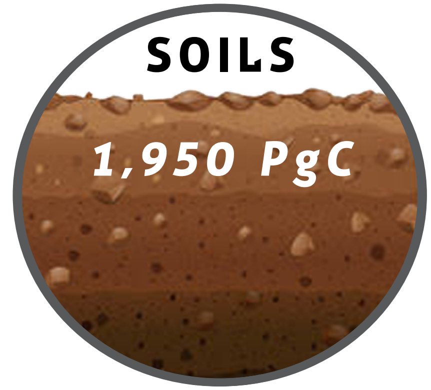
Cut a string 81 cm long, and tie the ends together to create a circle.
Circle area ≅ 520 cm^2

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).

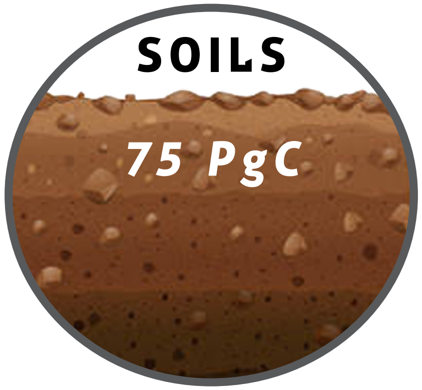
Cut a string 156 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,950 cm^2

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

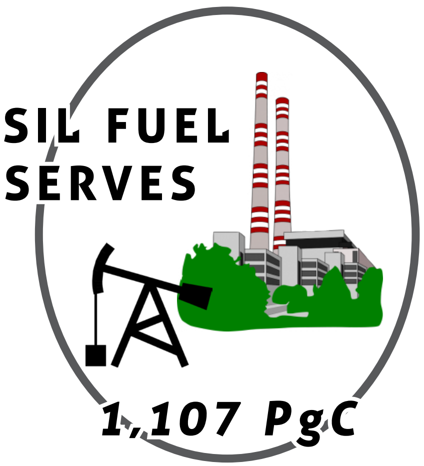
Respiration

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.

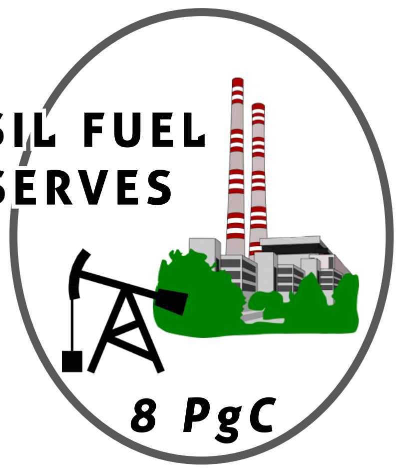
Cut a string 118 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,107 cm^2

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.

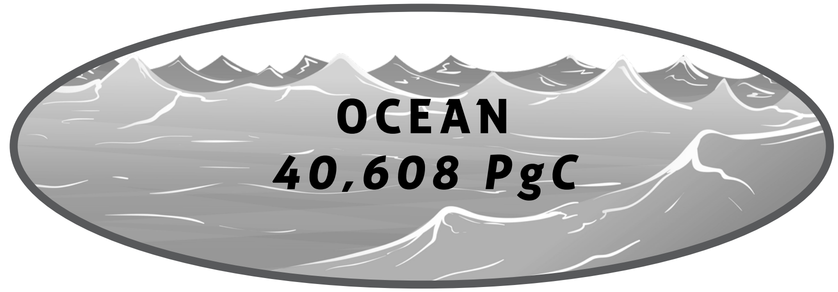
Cut a string 102 cm long, and tie the ends together to create a circle.
Circle area ≅ 829 cm^2

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.

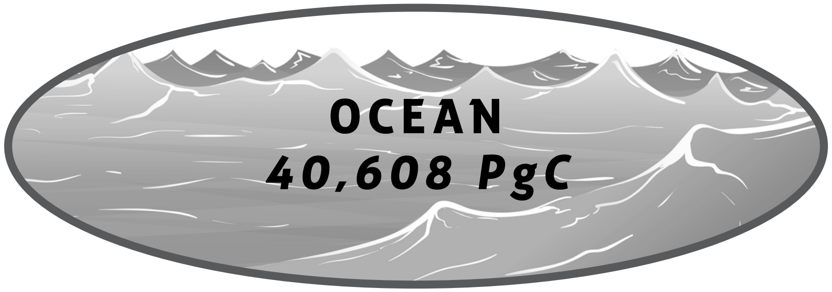
Cut a string 714 cm long, and tie the ends together to create a circle.
Circle area ≅ 40,608 cm^2

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

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

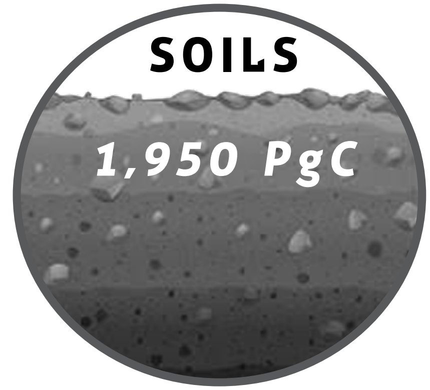
Cut a string 81 cm long, and tie the ends together to create a circle.
Circle area ≅ 520 cm^2

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).

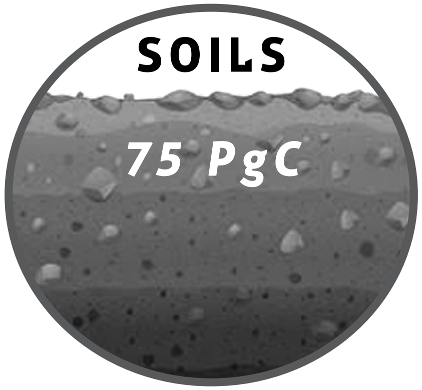
Cut a string 156 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,950 cm^2

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

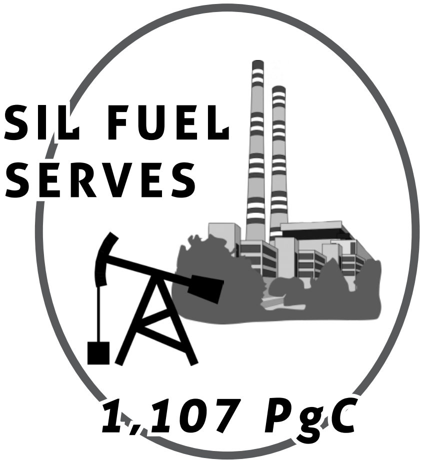
Respiration

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.

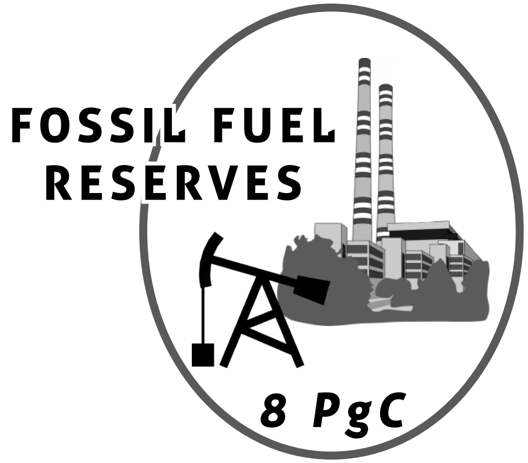
Cut a string 118 cm long, and tie the ends together to create a circle.
Circle area ≅ 1,107 cm^2

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

RESERVOIR TABLE TENTS

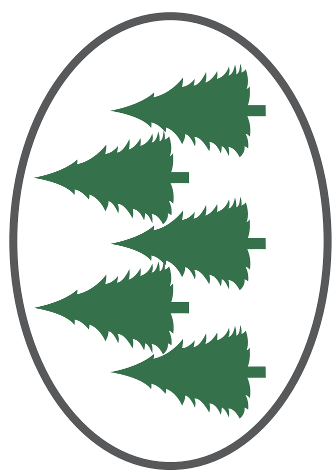
40,608 PgC

829 PgC

RESERVOIR TABLE TENTS

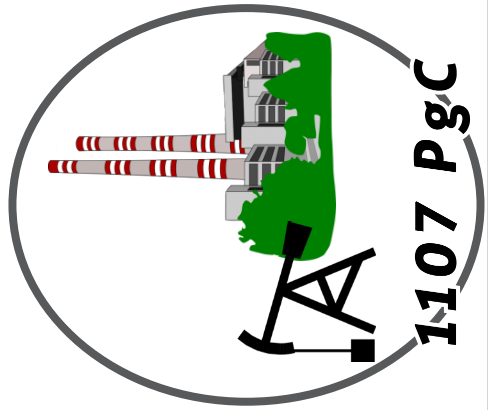
SOILS

VEGETATION



520 PgC

FOSSIL FUEL RESERVES



1107 PgC

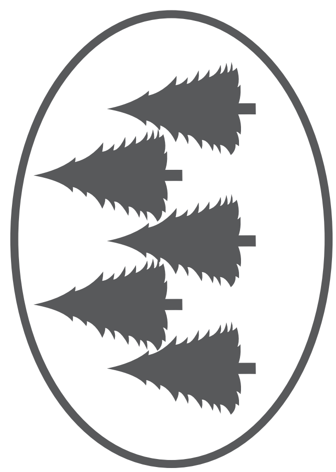
RESERVOIR TABLE TENTS

40,608 PgC

829 PgC

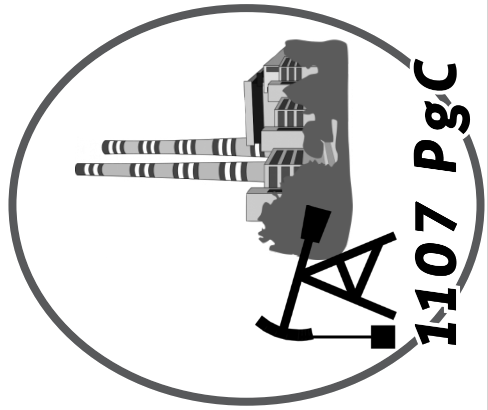
SOILS

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

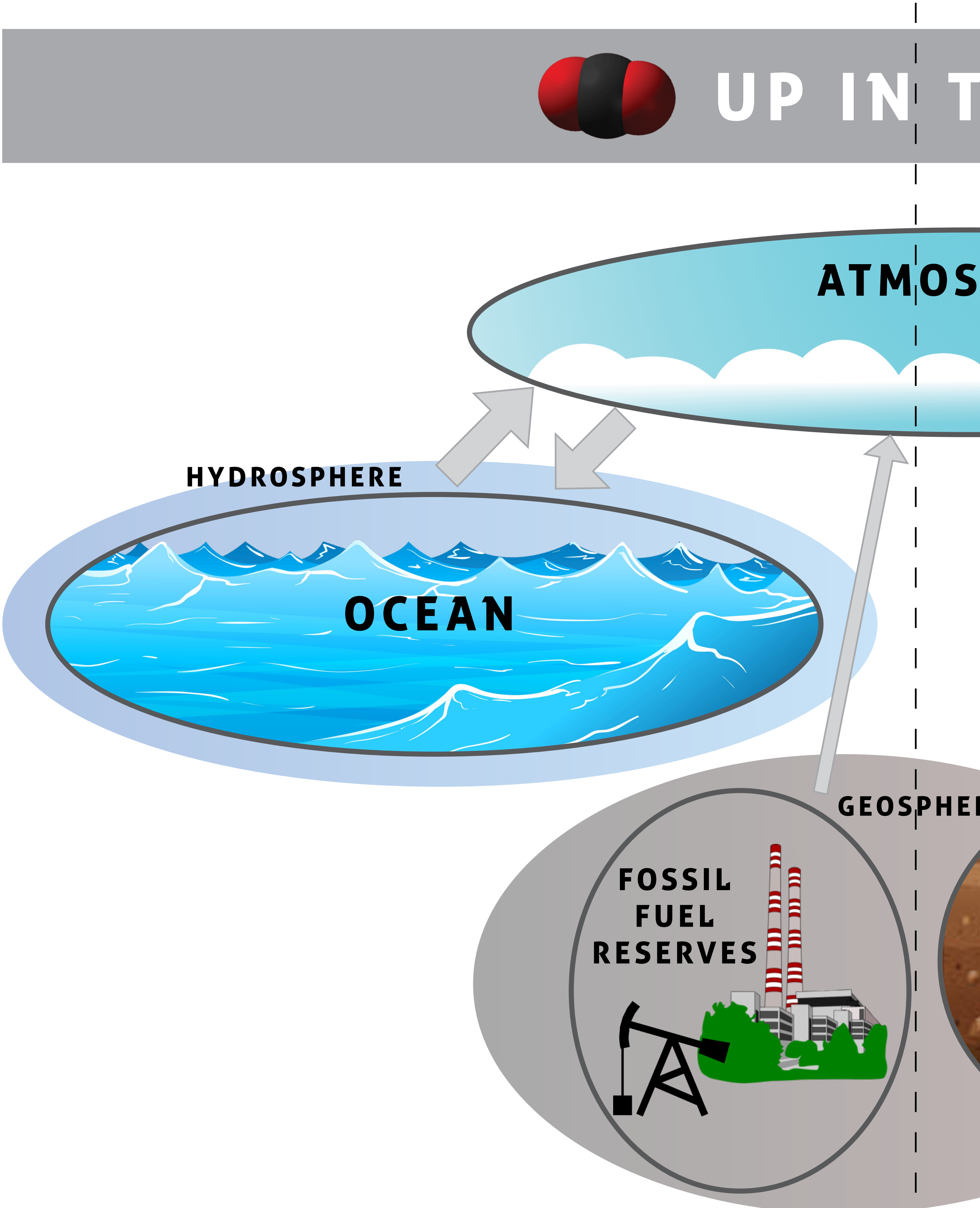
628 PgC

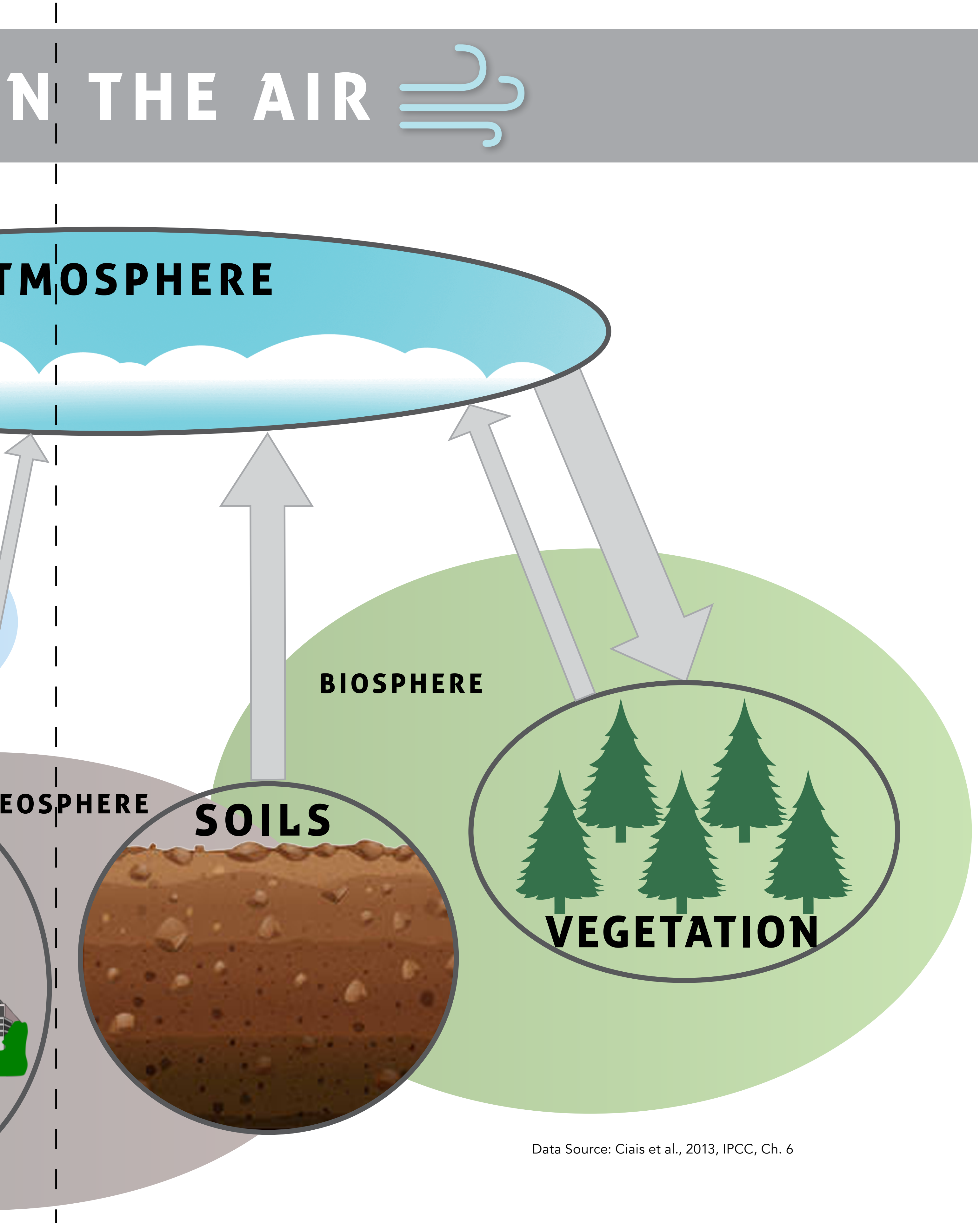
RESERVOIR NAME

1,099 PgC

RESERVOIR NAME

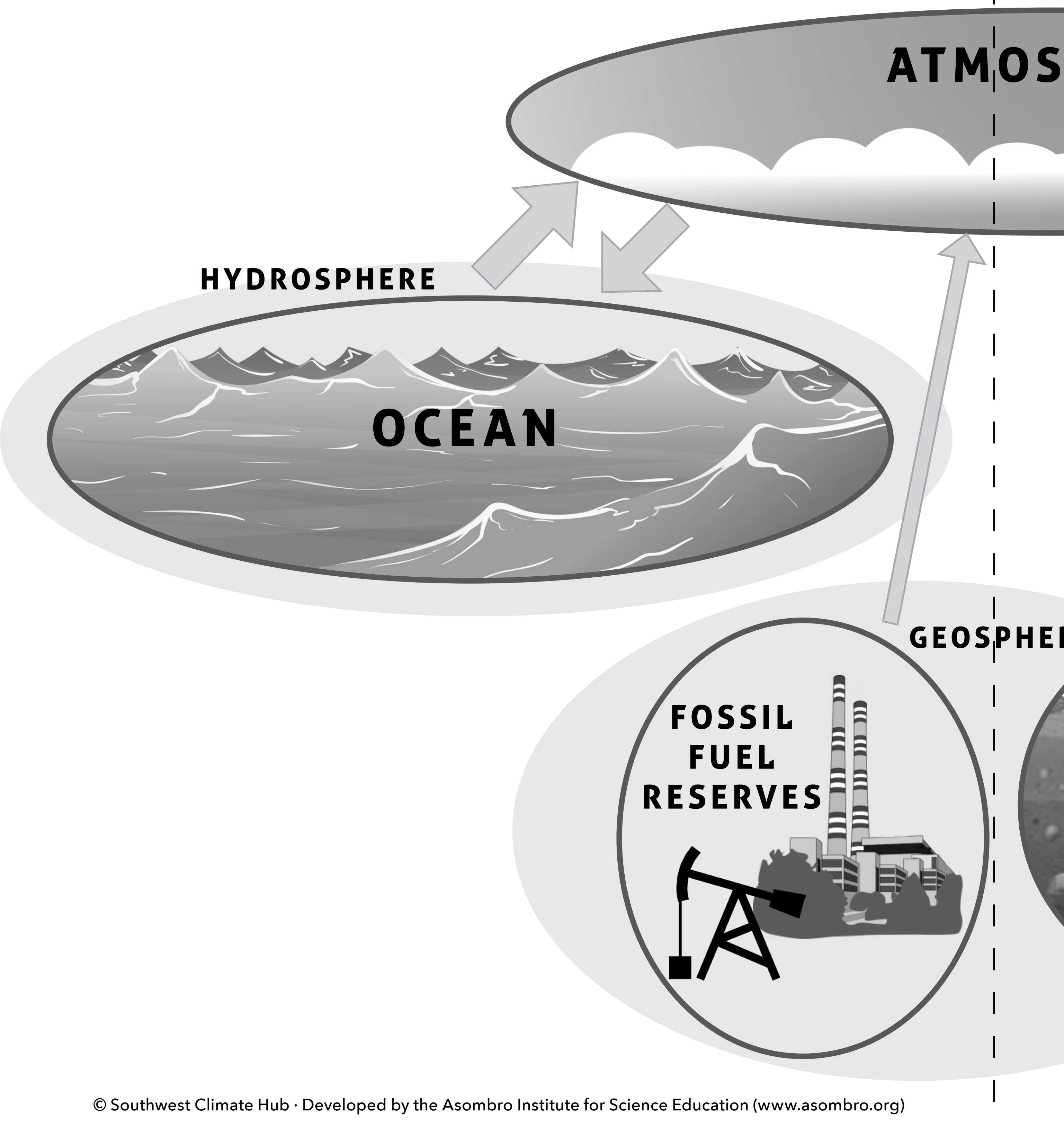
476 PgC


UP IN T
ATMOS
HYDROSPHERE
OCEAN
GEOSPHE
FOSSIL FUEL RESERVES

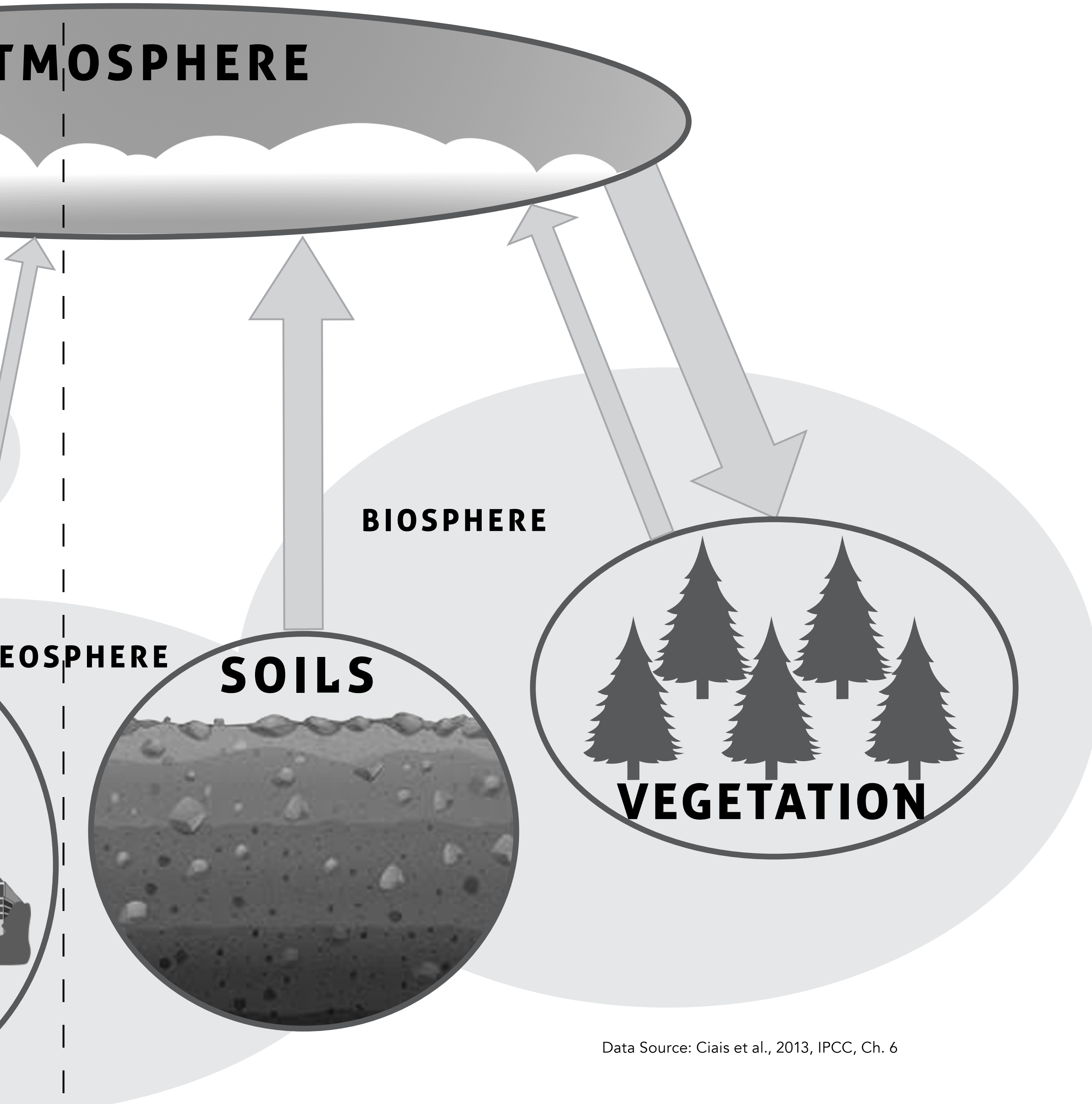


Data Source: Ciais et al., 2013, IPCC, Ch. 6

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

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

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		

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

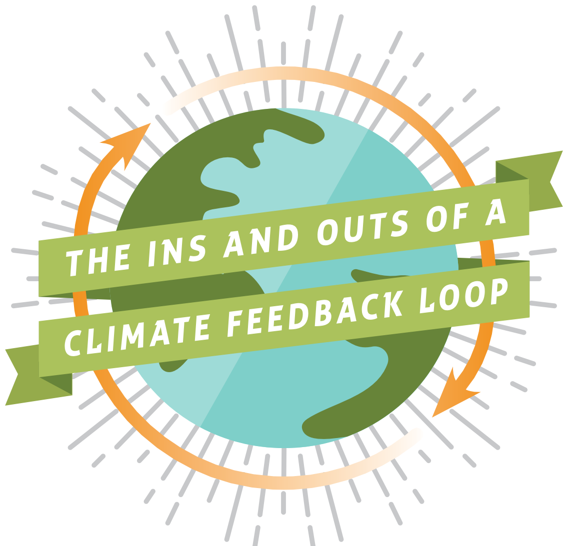
From Ocean to Atmosphere

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**



DESCRIPTION

Students learn how increasing atmospheric carbon dioxide is warming Earth's climate. They use the National Oceanic and Atmospheric Administration (NOAA) Interactive Atmospheric Data Visualization tool to investigate atmospheric carbon dioxide locally, conduct an experiment to model the greenhouse effect, and examine a positive feedback loop.

PHENOMENON

Carbon dioxide in the atmosphere is affecting temperatures on Earth, resulting in several positive feedback loops.

GRADE LEVEL
9-12

OBJECTIVES

Students will:

- Use models to generate data to support a scientific explanation
- Model the greenhouse effect
- Analyze the results of an experiment to provide evidence for a phenomenon
- Examine a positive feedback loop and explain how the inputs are destabilizing

TIME

1 HOUR FOR OPTION 1
45 MINUTES FOR OPTION 2

COMMON CORE STATE STANDARDS

English Language Arts

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

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.

Math

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

CCSS.MATH.CONTENT.HSS.ID.A.2. Use statistics appropriate to the shape of the data distribution to compare center (median, mean) and spread (interquartile range, standard deviation) of two or more different data sets.

NEXT GENERATION SCIENCE STANDARDS

Performance Expectation

HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Analyzing and Interpreting Data	ESS2.A: Earth Materials and Systems ESS2.D: Weather and Climate	Systems and System Models Stability and Change

BACKGROUND

The greenhouse effect keeps heat that radiates from the Earth's surface inside the atmosphere, ensuring that the planet is warm enough to sustain life. Since the Industrial Revolution, humans have been emitting increasing amounts of greenhouse gases into the atmosphere, mostly through energy production, transportation, and industry. Humans release more carbon dioxide than any other greenhouse gas. As additional carbon dioxide is released into the atmosphere, more of the thermal energy radiating from Earth is re-emitted back to the planet instead of escaping into space.

A greater concentration of atmospheric carbon dioxide and other greenhouse gases is causing average global temperatures to increase, forming several positive feedback loops. In the example in this activity, thermal expansion of water in the oceans is occurring, and ice sheets and glaciers are melting, which together are causing sea level rise. Rising sea levels are resulting in the destruction of coastal wetlands, such as tidal marshes and mangroves. Coastal wetlands are very effective at sequestering carbon, and with their destruction, atmospheric carbon dioxide will increase. In other words, the destruction of coastal wetlands magnifies the effect of the initial change, increasing carbon dioxide, resulting in a positive feedback loop.

MATERIALS

- Copies of The Ins and Outs of a Climate Feedback Loop handout [1 per student]
- PowerPoint presentation
- Computer and projector for educator
- Computers or tablets with internet access [1 per every 1-3 students]
  - If computers or tablets for students are not available, see options in Increasing Carbon Dioxide, Section 1
- Binder clips, size small (¾" wide) [1 per every four students]
- Calculators [1 per every four students or more if available]
- Hand towels (16" x 26" or larger) [1 per every four students]
  - If working with adults or older students, may also want a few small bath towels (27" x 52" or smaller)
- Mylar space/emergency blanket (Figure 1), cut into rectangles of approximately 20" x 26" or larger if needed [1 per every four students]
- Stopwatches [1 per every four students]
- Thermometers*, preferably ones with a probe and separate digital readout, such as the meat thermometer shown in Figure 2 [1 per every four students]
- *The Ins and Outs of a Climate Feedback Loop* instructional video, optional introduction to the experiment for the instructor

Figure 1. Example Mylar emergency/space blanket

Figure 2. Example meat thermometer with probe and digital readout

***Some notes about thermometers:**

- A thermometer without a probe and digital readout can be used. However, students will not be able to check the temperature readings every minute as instructed in this activity because they would have to lift the towel to read the thermometer, which would release the trapped heat. Instead, if using a thermometer without a probe, students should **only** read and record the temperature of the test subject's lap before placing the towel on top and after 5 minutes, immediately after removing the towel.
  - If a different type of thermometer is used, an alternative method of fastening the thermometer to the clothing on students' laps may be needed.
  - If a different type of thermometer is used, it is recommended that the educator try the experiment using their own lap several times before conducting the activity with students.
- Another option is an indoor-outdoor thermometer with a digital readout and wired sensor (such as the one found here: www.acurite.com/indoor-outdoor-thermometer-with-probe.html). However, in our testing of an indoor-outdoor thermometer, it seemed slower to respond and register changes in temperature, and students may not see as large of a temperature difference.

PREPARATION

You may choose the Full Lesson or Abbreviated Lesson based on time and technology constraints. The Full Lesson requires 1 hour and works best with an internet-connected computer or tablet for every 1-3 students (if computers or tablets for students are not available, see options in Increasing Carbon Dioxide, Section 1). The Abbreviated Lesson takes 45 minutes and does not require student computers or tablets.

Option 1: Full Lesson

1. Turn on internet-connected computers or tablets [1 for every 1-3 students].
2. On each device, open a web browser and display the NOAA Interactive Atmospheric Data Visualization website: https://www.esrl.noaa.gov/gmd/dv/iadv/ [You may use this shorter URL if entering manually: https://bit.ly/2q4t5Pw]

Option 2: Abbreviated Lesson

(Also complete these steps for the Full Lesson)

3. If possible, watch the *Ins and Outs of a Climate Feedback Loop* instructional video for an introduction to the experiment.
4. For Part II of the Presentation, the Greenhouse Effect experiment, plan to divide students into teams of four. If necessary, teams of three or five would also be acceptable, as activity tasks can be combined or divided.
5. Plan locations for the appropriate number of stations needed to accommodate the number of student teams in the group. Stations can be at student desks or tables and chairs with enough space for three to five students. No power source is needed.
6. Place a small binder clip, calculator, stopwatch, thermometer, and towel at each station. Also place a rectangle of space blanket at half of the stations.
7. Draw the "Whole Class" table from The Ins and Outs of a Climate Feedback Loop handout on the board, or prepare to show it with a document camera.
8. Set up a computer and projector, and display the PowerPoint presentation.

PROCEDURES

Options 1 and 2: Full and Abbreviated Versions

Begin here for both Full Lesson and Abbreviated Lesson

INTRODUCTION

1. If time permits, show an attention-grabbing viral video.
2. **Slide 2**: what do viral videos and carbon dioxide have in common? [Click to make the graphic appear.] They're both part of feedback loops. In a feedback loop, one thing affects another, and then the effect "feeds back in" to the original cause. In our example, a video gets shared, and then more people see it. Because more people have seen it, it's now likely to get shared even more. Once it receives a large number of views in a short amount of time, it is considered viral.

Option 1: Full Version

Continue here for Full Lesson or skip to Abbreviated Lesson below.

INCREASING CARBON DIOXIDE

NOAA Interactive Atmospheric Data Visualization

1. The introduction includes a web-based data visualization of atmospheric carbon dioxide concentrations from several sites across the United States. Using the National Oceanic and Atmospheric Administration (NOAA) Interactive Atmospheric Data Visualization tool, students and/or educators will access the closest carbon dioxide monitoring site to their geographic location on an interactive map. When teaching this, choose one of the following options, depending on the availability of laptops or tablets with internet access.
   a. Students conduct the activity independently or in groups on devices with internet access (preferred method).
   b. The educator uses the instructions below and a projector or other screen to show the entire class as s/he conducts the activity on a single computer with internet access.
   c. The educator conducts the activity before class, using the instructions below, and makes copies of one or two graphs for students to analyze.
2. Pass out a The Ins and Outs of a Climate Feedback Loop handout to each student.
3. **Slide 3**: today, we will investigate how carbon dioxide in the atmosphere is affecting temperatures on Earth, resulting in several positive feedback loops. We will be using an online tool to examine the amount of atmospheric carbon dioxide at a nearby site, and then we will conduct an experiment to model the effects of carbon dioxide on global temperatures. Throughout the lesson, we will put together just one example of a positive feedback loop resulting from carbon dioxide, although there are several others. Do not let the name fool you. Positive feedback loops do not always result in positive effects.
4. **Slide 4**: we will start by using the NOAA Interactive Atmospheric Data Visualization (IADV) online tool look at the amount of carbon dioxide in the atmosphere at the closest nearby monitoring site.
5. **Slide 5**: follow the instructions on your handout to open the NOAA website, if it is not open already, and choose the closest monitoring site from the map.
6. **Slides 6-13**: depending on your preferences and students, you can choose to skip slides 6-13 and allow students to follow the instructions on the handout independently. Otherwise, use slides 6-13 to go over the student instructions:

a. **Slide 6**: open this website if it is not already open: https://bit.ly/2q4t5Pw
b. **Slide 7**: use the "+" symbol to zoom in on the area of the world where you live.
c. **Slide 8**: hover over and then click on the red dot that is closest to where you live. Red dots indicate active sites.
    i. **Slide 9**: ensure that the name of the sampling location that you would like to use (closest to where you live) is listed in the first drop down menu at the top of the page.
d. **Slide 10**: in the drop down menus near the top of the page:
    i. Find programs, and choose "Carbon Cycle Gases."
    ii. Leave the other two drop down menus on their default settings.
        1. Popup detail: "Full"
        2. Active Sites: "All Sites"
e. **Slide 11**: in the right side bar, click on the "Carbon Cycle Gases" button.
    i. Two or more plot types will appear.
        1. Click on "Time Series."
f. **Slide 12**: you will be taken to another screen. Leave all options on their default settings.
    i. Parameter: "Carbon Dioxide"
    ii. Data Type: "Flask Samples" or "Aircraft Data"
    iii. Data Frequency: "Discrete"
    iv. Time Span: "All – a graph of all available data"
    v. Click the "Submit" button.
g. **Slide 13**: use the graph to answer Analysis Questions 1 and 2 on your handout.
h. If you'd like to choose another site and time allows, click the "Site Selection" button next to the small globe icon on the right side of the screen under the top banner. Follow these instructions again to create another graph.

Option 2: Abbreviated Lesson

Begin here for Abbreviated Lesson and continue for Full Lesson.

1. **Slide 14**: the phenomenon that we're investigating today is that carbon dioxide is affecting temperatures on Earth, resulting in several positive feedback loops. Let's think about what a positive feedback loop is for just a moment.
    a. In positive feedback loops, one thing affects another, and the impact is amplified. An increase in one thing results in an increase in the next thing, which increases the first thing again, and so on.
    b. In the viral video example, a video gets shared, and then more people see it. Because more people have seen it, it's now likely to get shared even more. It's a positive feedback loop. Positive refers to how the increase in one factor leads to an increase in another factor. We are not using "positive" in the same sense as "good." In our example here, a video getting shared and more people seeing it could generally be viewed as positive, meaning that they are good. However, in our next example, the increases in the positive feedback loop lead to consequences that are not good for Earth's systems.
2. **Slide 15**: we're going to look at one example of a positive feedback loop in this lesson that relates to how increased carbon dioxide is affecting Earth's temperature, but there are several others. If you used the IADV online tool, you saw that carbon dioxide is increasing no matter what site was selected. Scientists have been measuring atmospheric carbon dioxide at Mauna Loa in Hawaii since 1958, and you can see that it has been increasing. Increasing atmospheric carbon dioxide is a good place to start to build our positive feedback loop. We will add more pieces of the feedback loop as we move through the lesson.

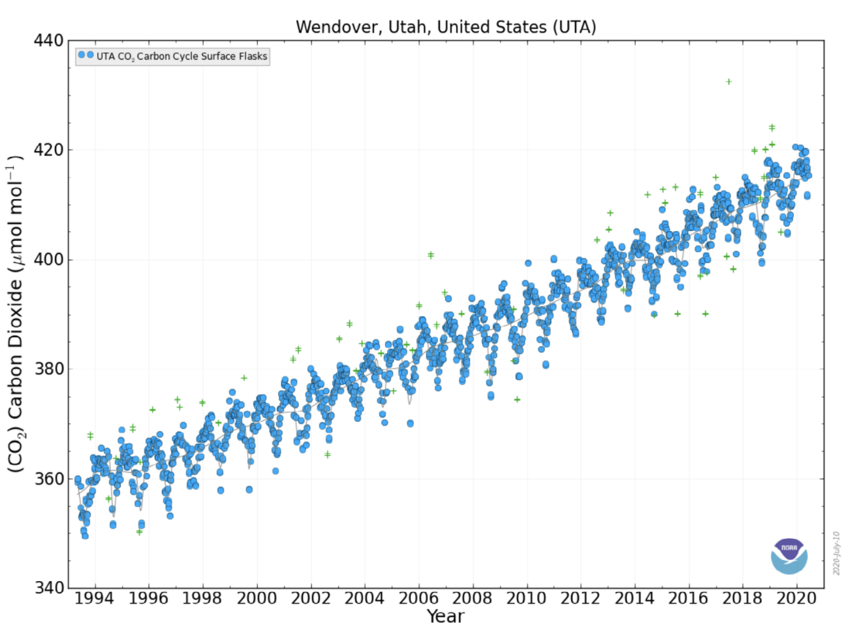


Figure 3. Example NOAA IADV graph from Wendover, UT

GREENHOUSE EFFECT

1. **Slide 16**: carbon dioxide is increasing in Earth's atmosphere. Let's think about why it matters with an experiment. Carbon dioxide is a greenhouse gas. We will conduct an experiment to model the effect of greenhouse gases on Earth's temperature.

2. Divide students into teams of four, and place students at stations.
3. Instruct students to read the team member roles on page 2 of the handout and choose one role for each student in the group.
4. **Slide 17**: the test subject will use a binder clip to attach the wire of the meat thermometer to the clothing on their lap. Instruct the student to point the metal probe toward their hip and attach the binder clip approximately halfway down the length of their thigh.
   a. (Figure 4). Ensure that the thermometer probe is contacting the student's thigh as much as possible. The probe should not be pointed sideways or hanging off of the student's lap.

Figure 4. Thermometer set up

5. The meat thermometer can take up to five minutes to accurately display the initial temperature of students' laps. Instruct students to watch the temperature casually and note whether it increases, decreases, or stays the same. Once students have their thermometers in place, take some time to explain the experiment and give a short introduction to the greenhouse effect as the thermometers adjust to their laps (steps 6-15).
6. Explain to the class that they will be conducting an experiment to determine which will insulate better: a single towel or a towel plus a space blanket on top. Tell students that the test subject in their group will place a towel over the thermometer and perpendicular to their thighs while demonstrating with one of the towels. Then, explain that half of the groups will also place a rectangle of space blanket on top while demonstrating with a towel and space blanket. Explain that the space blanket is made of Mylar, which is a good insulator (and also used for balloons), and it can be used as a blanket in emergencies. All groups will record the temperature every minute for five minutes.
7. Assign half of the student groups to conduct the "Towel Trial" and the other half of the student groups to conduct the "Towel + Space Blanket Trial." Instruct students to circle the trial that they have been assigned on page 2 of the handout.
8. Give a short introduction to the greenhouse effect using the PowerPoint presentation.
9. **Slide 18**: we have gases in our atmosphere that trap heat called greenhouse gases. They are: carbon dioxide, water vapor, ozone, methane, nitrous oxide, and fluorinated gases.
10. **Slide 19 (a)**: begin with the diagram on the left. The greenhouse effect ensures that Earth is warm enough for us to inhabit. Our atmosphere contains greenhouse gases, like carbon dioxide, methane, and nitrous oxide. Electromagnetic radiation from the sun, mostly at short wavelengths in the form of light, is able to pass through the atmosphere and is absorbed by Earth. Earth re-radiates some of this energy back toward space as heat, which is long-wave radiation. Most of the heat is able to pass through the atmosphere and escape into space, but some is absorbed by the atmosphere and then re-emitted back to Earth.
11. **Slide 19 (b)**: now explain the diagram on the right. [Click to make the graphic appear.] This is the enhanced greenhouse effect, which is caused by increased greenhouse gases in our atmosphere. As more greenhouse gases are released into the atmosphere, more of the re-radiated heat from Earth is re-emitted back to Earth instead of escaping to space. This is causing the average global temperature to increase.
12. **Slide 20**: this pie chart shows the percentage of each of the greenhouse gases that humans emit through our activities. Carbon dioxide accounts for 81% of the greenhouse gases that we release.
13. **Slide 21**: because carbon dioxide is the greenhouse gas that we emit in the largest amount, let's take a look at how we release it. Humans emit carbon dioxide mostly through fossil fuel combustion, i.e. the burning of coal, natural gas, and oil, for the production of electricity and transportation. Many industrial processes rely on fossil fuel combustion as well, and the production of mineral products, such as cement, the production of metals, and the production of chemicals can all result in carbon dioxide emissions.
14. **Slide 22**: remember the phenomenon that we are investigating today. Let's conduct an experiment to model the effect of carbon dioxide on Earth's temperature.
15. **Slide 23**: stop the presentation here, and display this slide while students are conducting the Towel and Towel + Space Blanket Trials.

Experimental Trials

16. Ask students to read the current temperature of their thermometers and tell you whether it has increased, decreased, or stayed the same since they clipped it to their clothing. The temperature should

have increased initially and then mostly stabilized.

17. Once the temperature has stabilized, direct each team's data recorder to record the temperature in the lap row of the Temperature column. The data recorder is the team member who is responsible for writing down all of the data during the experiment, but all students must complete the data table as well.
18. For groups conducting the Towel Trial, instruct the materials manager to give the towel to the test subject. For groups conducing the Towel + Space Blanket Trial, ask the materials manager to give the towel and then the space blanket rectangle to the test subject. For both trial groups, the test subject lays the towel over the thermometer and across their lap so that its long side is perpendicular to their thighs. In only the Towel + Space Blanket Trial groups, the test subject will then place the space blanket rectangle on top. Both should be oriented so that the long side is perpendicular to their thighs. If possible, the test subject should tuck the ends of the towel/blanket under their legs; if they will not tuck under, just ensure that they are covering the thermometer. See slide 23 for example photos of both trial setups.
19. As soon as the towel and space blanket (if applicable) are in place, instruct the timer to press the start button on the stopwatch.
20. Explain to the timer that for each minute that passes, they are to call out the time to the data recorder.
21. Explain to the data recorder that when the timer calls out the time, they are to read the temperature on the thermometer and record it in the corresponding row of the table.
22. Tell students to stop recording after 5 minutes.
23. The test subject can remove the towel, space blanket (if applicable), and thermometer.
24. Instruct students to answer question 3 in which they will calculate the difference in their group's ending and beginning trial temperatures.
25. Ask students to report the temperature difference from their trial to the class. Have students record their differences in the table on the board, or they can call them out to you while you write them on the board. Students must then record them in their "Whole Class" table on their handout and calculate the mean temperature difference for the Towel Trial and the Towel + Space Blanket Trial.
26. **Slide 24**: quickly review the left and right sides of the diagram, explaining the natural greenhouse effect and the enhanced greenhouse effect.
27. **Slide 25**: the experiment that you conducted was a model of the natural greenhouse effect and the enhanced greenhouse effect.
    a. Which item in the experiment modeled the earth? How it is like the earth? [Click to make the answer appear: the student's lap modeled the earth because it emits heat.]
    b. Which item in the experiment modeled the atmosphere? How it is like the atmosphere? [Click to make the answer appear: the towel modeled the atmosphere because the towel absorbed some of the heat and re-emitted it back toward the lap, effectively trapping it and keeping the lap warmer.]
    c. Which item in the experiment modeled additional carbon dioxide and other greenhouse gases? How it is like additional greenhouse gases? [Click to make the answer appear: the space blanket because, once it was added, more of the heat from the lap was re-emitted back to the lap instead of escaping into the room.]
28. Have students answer the Results and Conclusion questions 4-5.

WRAP UP AND FEEDBACK LOOP

1. **Slide 26**: Scientists have recorded data on Earth temperatures since 1880. NASA scientists created this graph showing the temperature anomalies every year. Scientists calculate temperature anomalies by comparing each year to average temperatures during a base period from 1951-1980. Temperature anomalies below zero are lower than the average temperatures during the base period, and those above zero are higher. Ask students to describe the trend of this graph [answer: temperature is increasing].
2. **Slide 27**: this graph shows both carbon dioxide, which is represented by the black line, and global temperature, which is represented by the blue and red bars (below and above the long-term average). Can you see a relationship? [answer: as carbon dioxide increases, global temperature increases.]
3. **Slide 28**: now we can add another piece to our positive feedback loop. Increasing carbon dioxide leads to increasing temperature.
4. **Slide 29**: over 70% of Earth is covered in oceans, so when thinking about the effects of increasing temperature, we must consider how it affects the oceans.
    a. Thermal expansion happens when thermal energy is transferred to water. Water molecules move faster when they are warmer, and they take up more space, causing the volume of water to increase.
    b. On average, glaciers have been losing mass since at least the 1970s, and there is a large photographic library of evidence, like the photos shown here from Plateau Glacier in Alaska, which has all but disappeared. Where does this melted water go? [answer: water from melting

ice sheets and glaciers flows into the ocean, which results in rising sea level.]

5. **Slide 30**: now we can add another piece of our positive feedback loop. Increasing temperature leads to melting ice and thermal expansion.
6. **Slide 31**: let's consider how melting ice and thermal expansion affect sea level with an example. Which city is this?
   a. [Click to make the city information appear.] This is Honolulu, Hawai'i. It is the state capital and largest city in Hawai'i and is estimated to have more than 350,000 people. The metro area of Honolulu, which includes the city and county of Honolulu, contains more than 950,000 people.
7. **Slide 32**: scientists at NOAA have created an online tool called the Sea Level Rise Viewer, which uses data on historic sea level rise and geographic information. Models were developed by scientists at the US Global Change Research Program to predict future sea level under different scenarios; NOAA used the models to create this tool which displays the impacts of sea level rise in the United States.
   a. We will examine Honolulu because it is an important US city that is particularly vulnerable to the effects of sea level rise.
   b. This first image shows Honolulu at current sea level.
8. **Slides 33-36**: we will move through these next few images quickly. Look for differences in where the water is as we move through the projected sea level rise in Honolulu every 20 years. [Flip through the slides quickly, narrating with as much of the information below as you have time to include.]
   a. **Slide 33** shows Honolulu just after the year 2020. In the circled area by the lagoon, flooding is going to start to occur in areas with buildings.
   b. **Slide 34** shows just after the year 2040 with a 2-foot projected sea level rise. In the same area by the lagoon, you can see that flooding is projected to move farther into these areas with buildings.
   c. **Slide 35** shows just after the year 2060 with a 4-foot projected sea level rise. A great deal of the populated areas with buildings along the coast are projected to experience flooding.
   d. **Slide 36** shows even more projected flooding all throughout the city, just after the year 2080 with a 6-foot projected sea level rise.
9. **Slide 37**: this the projected sea level at the turn of the century (the year 2100). Large portions of Honolulu are projected to be underwater. Imagine how many people will be affected and the impacts it will have on the city.
   a. In the state of Hawaii, it is estimated that over the next 30-70 years, approximately 6,500 structures and almost 20,000 people will be exposed to chronic flooding, and $19 billion in economic loss will result.
10. **Slide 38**: now we can add another piece to our positive feedback loop. Melting ice and thermal expansion lead to sea level rise.
11. **Slide 39**: what about coastal areas that are not heavily populated by people? Coastal wetlands, such as tidal marshes and mangroves, take up over 100 teragrams (Tg, i.e. trillion grams) of carbon globally per year. They take up more carbon per unit area than any natural system and are an important carbon reservoir. Coastal wetlands take up carbon so effectively by converting it to plant biomass more quickly than other ecosystems, trapping carbon in their sediments, and delaying the decomposition of organic matter, which releases carbon dioxide (Witman, 2017). Sea level rise threatens to disrupt this important ecosystem service of coastal wetlands. If they are destroyed by sea level rise, they will no longer be able to take up carbon.
12. **Slide 40**: let's think about how it all ties together. Carbon dioxide, global warming, sea level rise, and coastal wetland destruction are all part of a positive feedback loop. Remember, in a positive feedback loop, the increase of one factor causes the increase of another and so on. Positive feedback loops are destabilizing. The word stable means that something isn't changing. Positive feedback loops move a system away from its original state; they lead to change. In this case, the positive feedback leads to more warming. Remember, the effects of a positive feedback loop are not necessarily positive. Don't let the name fool you. Sometimes, such as in this example, the increases at each step of the loop lead to a negative impact on the system.
   a. As we saw in the NOAA IADV activity (or if not done, NOAA Mauna Loa atmospheric carbon dioxide graph), atmospheric carbon dioxide is increasing.
   b. [Click to make the text and graphic appear.] As we saw in the greenhouse effect experiment, increasing carbon dioxide leads to increasing global temperature.
   c. [Click to make the text and graphic appear.] Increasing global temperature leads to melting ice sheets and glaciers and thermal expansion.
   d. [Click to make the text and graphic appear.] Melting ice and thermal expansion lead to sea level rise.
   e. [Click to make the text and graphic appear.] Sea level rise leads to destruction of coastal wetlands.
   f. [Click to make the text and graphic appear.] Because

coastal wetlands are facing destruction and cannot continue to take up carbon as they are destroyed, carbon dioxide continues to increase even more.

g. This intensifies the original impact, which was increased atmospheric carbon dioxide, and the positive feedback loop continues.

13. **Slide 41**: remember, we conducted these activities today to examine this phenomenon. Carbon dioxide in the atmosphere is affecting temperatures on Earth, resulting in several positive feedback loops.
14. Now think about the evidence that you have gathered to understand and explain this phenomenon, and answer questions 6-8.
15. Time permitting, ask students to share their answers to questions 6-8, and discuss them.
16. **Slide 42**: what can we do? Technologies already exist to mitigate climate change (Pacala and Socolow, 2004). Mitigation means to reduce the impact to the environment or another resource. Mitigation can be used to reduce the amount of greenhouse gases released into the atmosphere. Strategies include using more electric cars, driving less, increased efficiency of power plants, increased use of biofuels, and increasing efficiency of building systems, such as heating and cooling, water heating, lighting, and refrigeration. Do you know of others?

EXTENSION

1. In small groups, have students conduct research on other climate feedback loops, choose a new feedback loop, develop a diagram and related questions, and ask the questions to fellow students.

ADDITIONAL RESOURCES

Environmental Protection Agency (EPA). Climate Change Indicators. Updated Aug. 2016. Web. Accessed 04 Mar. 2019. <https://www.epa.gov/climate-indicators/climate-change-indicators-glaciers>.

Global Climate Change, National Aeronautics and Space Administration (NASA). The study of Earth as an Integrated System. Updated 27 Feb. 2019. Web. Accessed 05 Mar. 2019. <https://climate.nasa.gov/nasa_science/science/>.

Hawai'i Climate Change Mitigation and Adaptation Commission (HCCMAC). 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.

Hopkinson, C.S., Cai, W., and X. Hu. 2012. Carbon sequestration in wetland dominated coastal systems – a global sink of rapidly diminishing magnitude. Current Opinion in Environmental Sustainability 4:1-9.

National Ocean Service, National Oceanic and Atmospheric Administration (NOAA). Is Sea Level Rising? Web. Accessed 04 Mar. 2019. <https://oceanservice.noaa.gov/facts/sealevel.html>.

Pacala, S. and R. Socolow. 2004. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science 305: 968-972.

Witman, S. 2017. Coastal wetlands effectively sequester "blue carbon," Eos, 98. Web. Accessed 19 Feb. 2020. <https://eos.org/research-spotlights/coastal-wetlands-effectively-sequester-blue-carbon>.

Name: ______________________________ Date: _______________ Period: _________

THE INS AND OUTS OF A CLIMATE FEEDBACK LOOP

NOAA INTERACTIVE ATMOSPHERIC DATA VISUALIZATION (IADV)

DIRECTIONS

Follow the instructions to create a graph, or use the information from your teacher. Then answer the analysis questions below.

A. Open this website if it is not already open: https://bit.ly/2q4t5Pw
B. Use the "+" symbol to zoom in on the area of the world where you live.
C. Hover over and then click on the red dot that is closest to where you live. Red dots indicate active sites.
   a. Ensure that the name of the sampling location that you would like to use (closest to where you live) is listed in the first drop down menu at the top of the page.
D. In the drop down menus near the top of the page:
   a. Find programs, and choose "Carbon Cycle Gases."
   b. Leave the other two drop down menus on their default settings.
      i. Popup detail: "Full"
      ii. Active Sites: "All Sites"
E. In the right side bar, click on the "Carbon Cycle Gases" button.
   a. Two or more plot types will appear.
      i. Click on "Time Series."
F. You will be taken to another screen. Leave all options on their default settings.
   a. Parameter: "Carbon Dioxide"
   b. Data Type: "Flask Samples" or "Aircraft Data"
   c. Data Frequency: "Discrete"
   d. Time Span: "All – a graph of all available data"
   e. Click the "Submit" button.
G. Answer Analysis Questions below.
H. If you'd like to choose another site and time allows, click the "Site Selection" button next to the small globe icon on the right side of the screen under the top banner.

NOAA IADV ANALYSIS QUESTIONS

1. Look at the graph, and circle the long-term trend for the years displayed. Over time, carbon dioxide (CO_2) in the atmosphere at the monitoring site:
   a. Increased
   b. Decreased
   c. Stayed the same
2. Make a claim. Given what you know, what are the effects of increasing concentrations of atmospheric CO_2 on Earth's temperature?

GREENHOUSE EFFECT

SETTING UP THE EXPERIMENT

1. Please work with your instructor to assemble into teams of 4.
2. Each team member will choose a role from the list of team member roles in the box to the right.
3. As quickly as possible, the team member who is the test subject will use a binder clip to attach the thermometer to the clothing on their lap. Attach the binder clip approximately halfway down the length of the thigh, and ensure that as much of the thermometer as possible is contacting the leg (Fig. 1).

TEAM MEMBER ROLES

Test subject

Materials manager

Timer

Data recorder

Figure 1. Example thermometer set up

MATERIALS

- Thermometer
- Small binder clip
- Stopwatch
- Hand towel
- Rectangle of space blanket
- Calculator

TRIAL ASSIGNMENT

Your instructor will assign your group to conduct either the Towel Trial or the Towel + Space Blanket Trial. **Circle** the trial that your group has been assigned.

Towel Trial **Towel + Space Blanket Trial**

PROCEDURES FOR TOWEL TRIAL

A. **Data recorder**, once the temperature reading of the test subject's lap has stabilized, record the temperature in the "Your Group" table on page 3. It can take several minutes for the temperature to stabilize. Enter the temperature under the "Temperature" column in the "Lap" row.
B. **Materials manager**, give the towel to the test subject. **Test subject**, lay the towel over the thermometer and across your lap so that its long side is perpendicular to your thighs, and tuck the ends of the towel under your legs if possible. **Timer**, press the start button on the stopwatch.
C. **Timer**, every time a minute passes on the stopwatch, call out the time to the data recorder. **Data recorder**, when the timer calls out the time, read the temperature on the thermometer and record it in the correct row of the table. Stop recording after 5 minutes. **Timer**, stop and reset the stopwatch.
D. **Test subject**, remove the towel and thermometer from your lap and give them to the materials manager.
E. Everyone in the group will transfer these measurements onto their own data table. Using these data, answer question 3.

PROCEDURES FOR TOWEL + SPACE BLANKET TRIAL

A. **Data recorder**, once the temperature reading of the test subject's lap has stabilized, record the temperature in the "Your Group" table on page 3. It can take several minutes for the temperature to stabilize. Enter the temperature under the "Temperature" column in the "Lap" row.
B. **Materials manager**, first give the towel and then the space blanket rectangle to the test subject. **Test subject**, lay the towel over the thermometer and across your lap, and then place the space blanket rectangle on top. Both should be oriented so that the long side is perpendicular to your thighs. Tuck both the towel and the space blanket under your legs together if possible. **Timer**, press the start button on the stopwatch.
C. **Timer**, every time a minute passes on the stopwatch call out the time to the data recorder. **Data recorder**, when the timer calls out the time, read the temperature on the thermometer, and record it in the correct row of the table. Stop recording after 5 minutes. **Timer**, stop and reset the stopwatch.

D. **Test subject**, remove the towel, space blanket, and thermometer from your lap and give them to the materials manager.
E. Everyone in the group will transfer these measurements onto their own data table. Using these data, answer question 3.

Report the temperature difference from your trial to the class. Record every group's differences, including your own, in the "whole class" table. Calculate the mean towel difference and the mean towel + space blanket difference. Answer the results and conclusions questions.

DATA COLLECTION AND ANALYSIS

Your Group	
Time	*Temperature*
Lap	°F
1 minute	°F
2 minutes	°F
3 minutes	°F
4 minutes	°F
5 minutes	°F

3. In your group, what was the difference between the ending temperature (5 minutes) and beginning temperature (lap)? Show your work.

Whole Class		
	Towel Difference	*Towel + Space Blanket Difference*
	°F	°F
	°F	°F
	°F	°F
	°F	°F
	°F	°F
	°F	°F
Mean		

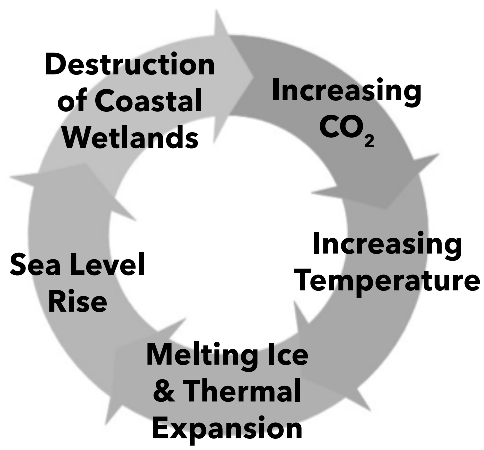
GREENHOUSE EFFECT RESULTS AND CONCLUSION QUESTIONS

4. In the **whole class table**, which trial had the greater mean difference? Circle one.

   a. Towel b. Towel + space blanket c. Same in both trials

5. Make a claim. Do the data from this model help support the scientific explanation for the greenhouse effect? Why or why not?

POSITIVE FEEDBACK LOOP



6. How is this positive feedback loop destabilizing?

7. In the diagram above, circle the point at which humans can have the most influence on the positive feedback loop.

8. What are some ways that humans can reduce the amount of atmospheric carbon dioxide that we emit?

ANSWER KEY

THE INS AND OUTS OF A CLIMATE FEEDBACK LOOP

NOAA INTERACTIVE ATMOSPHERIC DATA VISUALIZATION (IADV)

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Follow the instructions to create a graph, or use the information from your teacher. Then answer the analysis questions below.

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C. Hover over and then click on the red dot that is closest to where you live. Red dots indicate active sites.
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D. In the drop down menus near the top of the page:
   a. Find programs, and choose "Carbon Cycle Gases."
   b. Leave the other two drop down menus on their default settings.
      i. Popup detail: "Full"
      ii. Active Sites: "All Sites"
E. In the right side bar, click on the "Carbon Cycle Gases" button.
   a. Two or more plot types will appear.
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   a. Parameter: "Carbon Dioxide"
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1. Look at the graph, and circle the long-term trend for the years displayed. Over time, carbon dioxide (CO_2) in the atmosphere at the monitoring site:
   a. Increased (circled)
   b. Decreased
   c. Stayed the same
2. Make a claim. Given what you know, what are the effects of increasing concentrations of atmospheric CO_2 on Earth's temperature?
   Student answers will vary, depending on prior knowledge, but may include the following explanation. As atmospheric carbon dioxide increases, global temperature will increase because of the greenhouse effect.

GREENHOUSE EFFECT

SETTING UP THE EXPERIMENT

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Figure 1. Example thermometer set up

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C. **Timer**, every time a minute passes on the stopwatch, call out the time to the data recorder. **Data recorder**, when the timer calls out the time, read the temperature on the thermometer and record it in the correct row of the table. Stop recording after 5 minutes. **Timer**, stop and reset the stopwatch.
D. **Test subject**, remove the towel and thermometer from your lap and give them to the materials manager.
E. Everyone in the group will transfer these measurements onto their own data table. Using these data, answer question 3.

PROCEDURES FOR TOWEL + SPACE BLANKET TRIAL

A. **Data recorder**, once the temperature reading of the test subject's lap has stabilized, record the temperature in the "Your Group" table on page 3. It can take several minutes for the temperature to stabilize. Enter the temperature under the "Temperature" column in the "Lap" row.
B. **Materials manager**, first give the towel and then the space blanket rectangle to the test subject. **Test subject**, lay the towel over the thermometer and across your lap, and then place the space blanket rectangle on top. Both should be oriented so that the long side is perpendicular to your thighs. Tuck both the towel and the space blanket under your legs together if possible. **Timer**, press the start button on the stopwatch.
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Your Group	
Time	***Temperature***
Lap	°F
1 minute	°F
2 minutes	°F
3 minutes	°F
4 minutes	°F
5 minutes	°F

Student answers will vary

3. In your group, what was the difference between the ending temperature (5 minutes) and beginning temperature (lap)? Show your work.

Student answers will vary

Whole Class		
	Towel Difference	***Towel + Space Blanket Difference***
	°F	°F
	°F	°F
	°F	°F
	°F	°F
	°F	°F
	°F	°F
Mean		

Student answers will vary

Student answers will vary

GREENHOUSE EFFECT RESULTS AND CONCLUSION QUESTIONS

4. In the **whole class table**, which trial had the greater mean difference? Circle one.

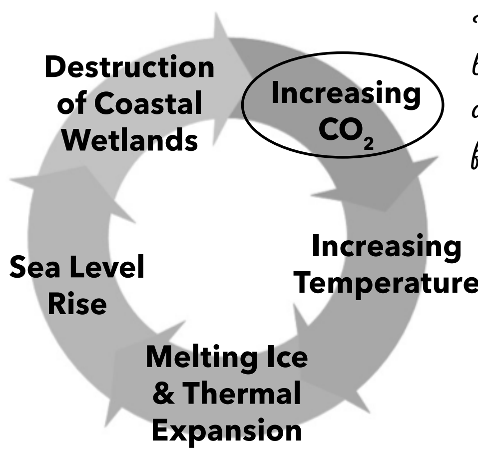
   a. Towel   b. Towel + space blanket   c. Same in both trials

   This is usually the case

5. Make a claim. Do the data from this model help support the scientific explanation for the greenhouse effect? Why or why not?

   Student answers will vary but should include at least some of the following explanations. Yes, these data support the explanation that adding greenhouse gases, modeled by the space blanket, will result in more of the heat that is radiated from Earth being re-radiated back toward Earth instead of escaping to space. The towel + space blanket trial had a greater mean difference. In other words, the temperature increase was greater in the trials with a space blanket, and adding greenhouse gases to the atmosphere is like adding a space blanket and is resulting in global temperature increases.

POSITIVE FEEDBACK LOOP



We could have the largest impact by reducing the amount of carbon dioxide that we release by burning fossil fuels.

6. How is this positive feedback loop destabilizing?

   The feedback loop is destabilizing because it leads to more warming and moves the system away from the original state, lower global temperature.

7. In the diagram above, circle the point at which humans can have the most influence on the positive feedback loop.

8. What are some ways that humans can reduce the amount of atmospheric carbon dioxide that we emit?

   There could be a number of answers, including reducing electricity use, improving building efficiency, switching to renewable energy sources, such as solar and wind, carbon capture and storage from fossil fuel powered electricity plants, using more electric vehicles, improving vehicle fuel efficiency, carpooling, using public transportation, walking, riding a bicycle, recycling, reusing, and reducing the amount of consumption of factory-produced materials and other goods.

Climate Change

Mitigation

DESCRIPTION

Students investigate actions that individuals can take to decrease their carbon emissions and mitigate climate change. They consider a strategy from several perspectives and analyze the associated benefits and challenges. Students then create a poster to present their analysis of a mitigation strategy and the pros and cons of implementing it.

PHENOMENON

There are many proposed strategies individuals can take to mitigate climate change, but implementing them comes with pros and cons that should be considered.

GRADE LEVEL 9-12

OBJECTIVES

Students will:

- Explain how mitigation strategies can slow or lessen the effects of climate change
- Analyze the challenges and benefits of an individual action to mitigate climate change
- Develop solutions to overcoming the challenges in implementation of an individual mitigation strategy

TIME

45-MINUTES

COMMON CORE STATE STANDARDS

English Language Arts

CCSS.ELA-LITERACY.RI.9-10.8 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.RI.11-12.7 Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem.

CCSS.ELA-LITERACY.W.9-12.1 Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.

CCSS.ELA-LITERACY.W.9-12.2 Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.

NEXT GENERATION SCIENCE STANDARDS

Performance Expectation

HS-ESS3-4 Evaluate or refine a technological solution that reduces the impacts of human activities on natural systems.

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions	ESS3.C Human Impacts on Earth Systems ESS3.D Global Climate Change ETS1.B Developing Possible Solutions	Stability and Change

BACKGROUND

Since the Industrial Revolution, fossil fuel extraction and combustion have 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. Several technologies already exist that, when used in combination, can mitigate the effects by reducing or eliminating carbon emissions while meeting the world's energy needs. These include increased vehicle efficiency, building efficiency, power plant carbon capture and storage, wind power, and solar power (Pacala and Socolow, 2004). Scientists have also identified strategies that individuals can implement to reduce their carbon emissions, including having one fewer child, switching to a hybrid car or car-free life, limiting air travel, and eating a plant-based diet (Wynes and Nicholas, 2017). Students evaluate these actions for their feasibility, effectiveness of mitigating climate change, and their social and economic impacts.

MATERIALS

- PowerPoint presentation
- Computer and projector for educator
- Copies of Mitigation Strategy pages, black and white or color [1 set per group]
- Copies of Mini-poster [1 set per group]
- *Optional:* Copy of Stakeholder Cards, copied onto cardstock and cut [1 per class]

PREPARATION

1. Set up a computer and projector and display the PowerPoint presentation.
2. If your students do not have a basic understanding of climate change and the greenhouse effect before starting this activity, you may wish to show or assign one or more of the videos in the extensions section at the end of this guide.
3. Make one Mini-poster for every group of students. Cut each page along the dotted line, align the pages, and tape them together. Alternatively, you may plan to have students assemble their Mini-posters if time permits.
4. If you are using the Stakeholder Cards, copy one set of cards onto cardstock (if available), and cut on the dotted lines.

PRESENTATION

INTRODUCTION

1. **Slide 2**: carbon moves around the planet via the carbon cycle. Humans have modified the carbon cycle by burning fossil fuels, which release carbon, in the form of carbon dioxide, into the atmosphere.
2. **Slide 3**: carbon dioxide is a greenhouse gas that traps heat inside the atmosphere. This causes many changes to the earth's climate and also results in feedback loops, which release even more carbon dioxide into the atmosphere. For example, warming the atmosphere melts the polar ice caps, causing sea levels to rise. Sea level rise destroys coastal ecosystems, which take up carbon dioxide from the atmosphere more quickly than most other ecosystems, resulting in more carbon dioxide in the atmosphere. If time permits, discuss one or more of the other examples listed on the slide:
   - Disease spread: The distribution of disease vectors such as mosquitos, fleas, and ticks is limited by climate. A changing climate may allow these animals to spread to new habitats and increase disease risks.
   - Growing season changes: Warmer temperatures earlier in the year are expanding plant growing seasons, which may be beneficial in agriculture.
   - Habitat loss: For some species, changes in temperature and precipitation are making their current habitats uninhabitable. Many marine mammals are moving towards the poles in search of cooler water as ocean temperatures rise.
   - Extreme weather patterns: Changing ocean and air temperatures lead to stronger and more frequent hurricanes and tornadoes. Climate change models also predict more intense droughts and winter storms in the future.
3. **Slide 4**: give students a minute to brainstorm major ways humans release carbon into atmosphere and ways that humans reduce or prevent the release of carbon into the atmosphere. [Answers for releasing carbon may include: using cars and other transportation, burning coal and gas for electricity, cutting down trees, and raising livestock. Answers for reducing carbon emissions might include: driving less, biking, walking, using renewable energy, conserving energy, planting trees, and reducing, reusing, and recycling.]

MITIGATION

1. **Slide 5**: mitigation is any action that reduces the severity of something. Climate change mitigation strategies slow or lessen the effects of climate change by reducing the amount of greenhouse gases entering the atmosphere or by removing them from the atmosphere. The data in this infographic is from a study (Wynes and Nicholas, 2017) that investigated the most effective ways for individuals to reduce their carbon emissions. Today, you will choose one of the strategies to analyze and refine.
2. **Slide 6**: mitigation of any problem is complicated, with sound arguments that can be raised for or against any action. The strategies in the previous slide have been researched extensively, and implementing them can reduce carbon emissions. However, there are social, cultural, economic, and safety challenges with all of them. It is your job to think critically about these challenges, try to address them, and determine if the strategy is feasible.
3. **Slide 7**: as a class, you will analyze one strategy together. Solar energy is electricity generated by solar panels. Scientists have estimated that carbon emissions would be reduced by 0.5 Pg/year (Pg or petagram is equal to 10^{15} grams, or approximately the weight of 6 million blue whales) if we replaced 1000 GW of coal-generated electricity with solar-generated electricity. This would require three billion solar panels. A few

challenges to implementing solar energy and a few steps that could help to make it happen are listed on the slide.

   a. [Optional] To encourage students to examine this strategy from a variety of perspectives, you can pass out one Stakeholder Card to each student. Ask them to think about the idea of using solar energy from the perspective on their card. Give students a minute to read their card and discuss with their neighbor the opinions their stakeholder might have about solar energy.

4. **Slide 8**: what are the biggest challenges to using solar energy? [Possible answers: the space needed for solar panels, the initial set up costs, resistance from the fossil fuel industry, the difference between peak energy production times and peak energy use times, and a limited supply of materials for solar panels and batteries.]
   a. [Optional, if using Stakeholder Cards] Which stakeholders in the room have a strong argument against using solar energy?
5. **Slide 9**: whose responsibility is it to lead the effort to transition to solar energy? Is it up to individuals, corporations, governments, or someone else? Where in the world could this happen? Can poor countries implement solar energy? Are there parts of the world where it would be a bad idea to build solar farms? For example, it rains and it overcast a lot in Seattle, so that is probably not a good place for solar farms. There is plenty of space in Antarctica, but there is little sunlight there during half of the year.
   a. [Optional, if using Stakeholder Cards] Which stakeholders have a responsibility to lead the effort to transition to solar energy?
6. **Slide 10**: who will pay for installing solar panels? Should it be individual people who want them, the government, or power companies? Who will benefit? [Possible answers: everyone gets cleaner air; power companies don't have to mine coal anymore; businesses that build solar panels will expand.] Who will be hurt by it? [Possible answers: people who currently work in the fossil fuel industry may lose their jobs. Places where the materials for solar panels are mined could be harmed.]
   a. [Optional, if using Stakeholder Cards] Can/would any of the stakeholders take responsibility to help pay for solar panels?
7. **Slide 11**: what are the pros and cons of switching to solar energy? [Possible answers for pros: cleaner air and water, less expensive energy in the long run, will slow climate change, and will save people money. Possible answers for cons: will cost a lot of money up front, thousands of people rely on the coal and gas industry for jobs, and solar panels are made with materials that have to be mined, harming the environment.] Does investing in solar energy mean that you are ignoring another type of renewable energy that could be more effective? Hydroelectric, tidal, geothermal, and wind energy might be better options in some places.
   a. [Optional, if using Stakeholder Cards] Are there any stakeholders that would like to share the pros and cons of switching to solar energy from their perspective?
8. **Slide 12**: if you were in charge of making sure we switch to solar energy, how would you do it? Where would you find space? How would you address the cost? Would you need to change people's habits or the law to make sure it happens?
9. **Slide 13**: this slide is an example of a Mini-poster that summarizes our evaluation of the strategy. Question 7 on the poster asks how to address the challenges that the class identified.

ANALYZE A MITIGATION STRATEGY

1. Divide students into small groups, pairs, or choose to have them work individually.
2. Pass out a set of Mitigation Strategy pages and a copy of the Mini-poster to each group.
3. **Slide 14**: each group will choose one of the five mitigation strategies from the Mitigation Strategy pages to analyze and refine.
   a. Each group will create their own Mini-poster like the one for solar energy on the previous slide. The Mini-poster has several questions to help you consider different aspects of your proposed strategy.
   b. You can use the Mitigation Strategy pages to get started, but most of the information you will fill out on your poster will not be included on the pages. You will have to think critically about the world to come up with a strategy you think will work to mitigate climate change.
   c. Try to consider the strategy from many different perspectives, just like we did in the solar energy example.
      i. [Optional] If you chose to use the Stakeholder Cards for the class example discussion of solar panels, students will not be using them for this activity. Simply instruct them to keep in mind the perspectives of all the stakeholders as they complete the activity.
   d. Discuss and answer all of the questions on the poster before answering question 7 because you might come up with ways to improve the strategy as you discuss and think about the challenges, pros, and cons.
4. **Slide 15**: this slide shows all the mitigation strategies proposed in the paper mentioned earlier. Leave this up as students

begin their work. You may give students the rest of class to work, or you may stop them 10 minutes before the end of class to share their strategies and have a class discussion about which strategies will be most successful and are most feasible.

EXTENSIONS

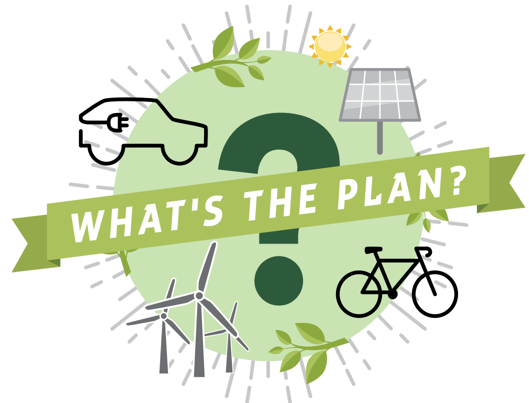
1. If you have access to computers, students can do their own research on their mitigation strategy to find other challenges and solutions they have not considered or to search for examples of successful implementation of the strategy.
2. Display the infographic on slide 5 and have students choose one of the mitigation actions and conduct one or both of the following:
   a. Create a plan for how they could incorporate one of the mitigation actions into their own lives.
   b. Develop a public education effort in their community to raise awareness about the strategy. After conducting more research as needed, students could create graphics for social or print media, create a video advertisement for television, YouTube, or TikTok, and/or write a letter to the editor of the local paper, for example.
3. If students need more background on climate change, you may want to show or assign one of these videos:
   - CIRES videos- Our Shared Climate Future https://www.youtube.com/watch?v=sGrQdLH1K74
     - This video explains the greenhouse effect, the science of measuring atmospheric carbon dioxide, and the impacts of warming on the planet.
   - Global Weirding- Southern Great Plains & Southwest https://www.youtube.com/watch?v=wd6w6mTQGwc
     - This video explains the region-specific impacts of climate change, including extreme weather events, drought, wildfire, and enhanced climate variability. It does not include an explanation of the greenhouse effect. The Global Weirding with Kathrine Hayhoe YouTube Channel is created by PBS Digital Studios and Texas Tech University Public Media and has videos on every region of the US.
   - Intergovernmental Panel on Climate Change (IPCC)- Climate Change 2013: The Physical Science Basis. https://www.youtube.com/watch?v=6yiTZm0y1YA&feature=player_detailpage
     - This video is fairly technical. It is appropriate for older students who have some familiarity with climate change and the greenhouse effect.

ADDITIONAL RESOURCES

Pacala, S. and R. Socolow. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 305: 968-972.

Wynes, S. and K.A. Nicholas. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

MITIGATION STRATEGY: FUEL EFFICIENT CARS



The fuel efficiency of an average car is 30 miles per gallon (mpg), but the popular hybrid car below is estimated to achieve up to 58 mpg. A typical passenger car emits 4.6 metric tons of carbon dioxide per year (EPA, 2018). It is estimated that there are currently over 1 billion vehicles in the world, and there will be 2 billion by 2035. Owners of hybrid cars usually spend less on gas because the car is more efficient, but hybrid cars usually cost more than average cars, making it hard for some to afford them. Scientists have calculated that carbon emissions would be reduced by 1 Pg/year if we replaced 2 billion average cars with fuel efficient cars.[1] One person can reduce their carbon emissions by 0.52 metric tons of carbon per year by switching from a traditional to hybrid car.[2]

WHAT COULD HELP MAKE THIS HAPPEN:

- Governments could offer a tax credit to offset the cost of the car.
- A new law could require new cars to be more fuel efficient.
- Allow fuel efficient cars to use the carpool or HOV lanes to avoid traffic.

CHALLENGES:

- Hybrid and electric cars are more expensive.
- Fuel efficient cars are usually smaller and less powerful than standard cars.
- Car manufacturing plants are set up to make standard cars; making new types of cars requires them to change their factory set up and equipment.

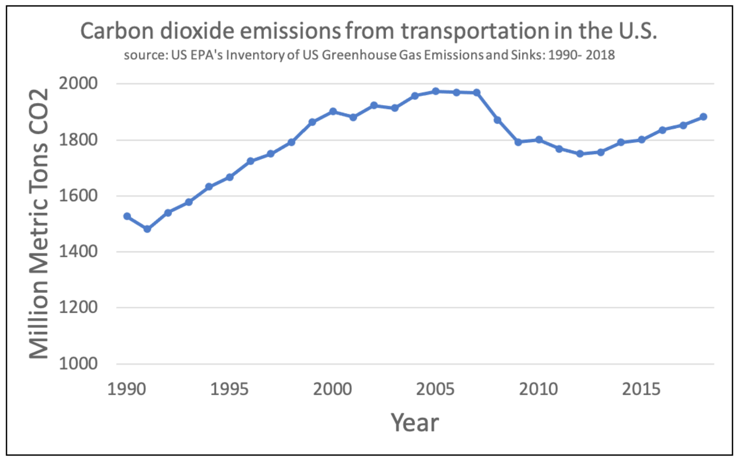
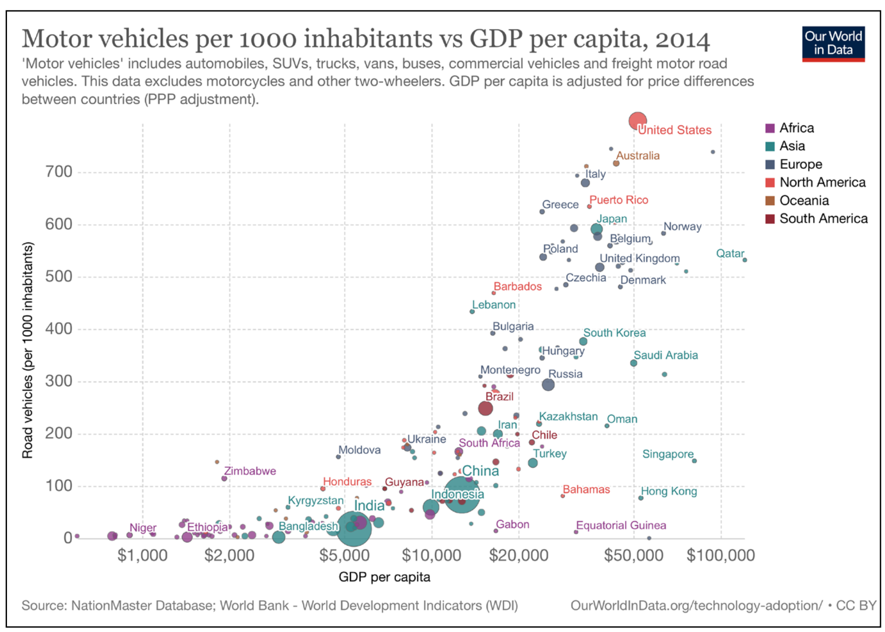


Photo credit: Toyota (toyota.com/search/search.html?keyword=prius)

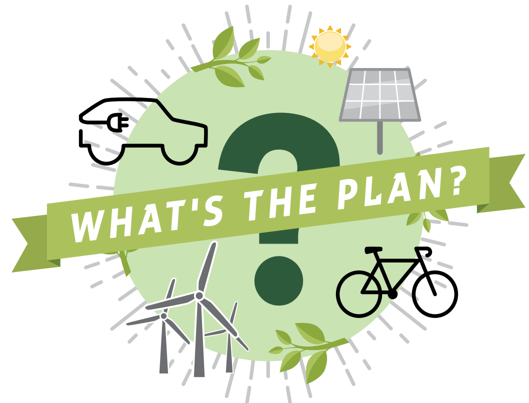
Image credit (right): Our World in Data (https://ourworldindata.org/grapher/road-vehicles-per-1000-inhabitants-vs-gdp-per-capita?time=latest&country=USA~BRB)



1. Pacala, S. and R. Socolow. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 305: 968-972.

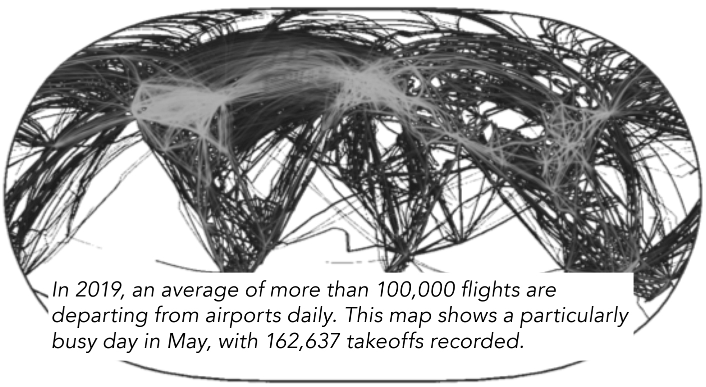
2. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

3. Environmental Protection Agency. 2020. Inventory of US Greenhouse Gas Emissions and Sinks 1990-2018



MITIGATION STRATEGY: DECREASE AIR TRAVEL

Traveling by airplane emits large amounts of carbon into the atmosphere due to burning fuel. The United Nations (2019) predicts CO_2 emissions from air travel could triple by 2050. A round trip from New York to San Francisco generates approximately 1 metric ton of CO_2 per passenger. Eliminating or minimizing air travel is often claimed to be one of the most effective ways an individual can decrease their carbon emissions. Compared to traveling by car, the greenhouse gas emissions per passenger traveling by plane are much higher, especially for shorter distances. A family of four driving from Los Angeles to San Francisco generates about a third of the CO_2 that flying would generate. According to a NASA (2010) study, most of the emissions generated by planes are from take off and landing. Scientists have calculated that avoiding one transatlantic flight per year will save 1.6 metric tons of CO_2,[1] or decrease the average American's carbon emissions by 10%.



In 2019, an average of more than 100,000 flights are departing from airports daily. This map shows a particularly busy day in May, with 162,637 takeoffs recorded.

Image Credit: The Guardian (https://www.theguardian.com/environment/ng-interactive/2019/jul/19/carbon-calculator-how-taking-one-flight-emits-as-much-as-many-people-do-in-a-year)

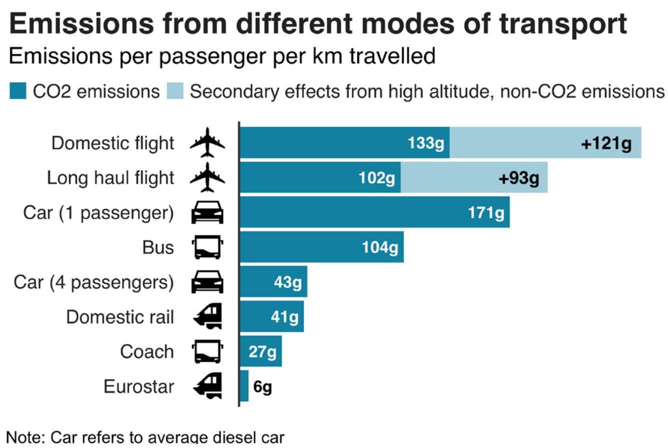


Image Credit: BBC (https://www.bbc.com/news/science-environment-49349566)

WHAT COULD HELP MAKE THIS HAPPEN:

- Normalizing telework and work-from-home so traveling for business becomes less necessary.
- Using alternate methods of travel – more long distance and fast buses and trains.
- Choosing nonstop flights to decrease the number of take offs and landings during a trip.
- Educate people about the carbon costs of travel (e.g. an app that tells you how much carbon a trip releases).
- Purchase carbon offsets if flights are required.
- Discourage private jet flights.

CHALLENGES:

- 30% of American air travel is business-related travel, not personal choices.[3]
- When there is only one person in the car, carbon emissions from a long road trip are actually higher than from flying.[2]
- Flying is convenient and fast.
- There are not easy alternatives to flying (e.g., high speed trains) in the U.S.

Flying from Los Angeles (LAX) to New York John F. Kennedy (JFK)

Flying from Los Angeles to New York John F. Kennedy and back generates about 697 kg CO_2. There are 50 countries where the average person produces less CO_2 in a year.

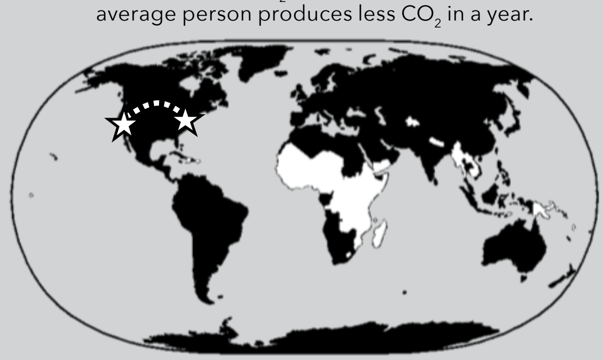


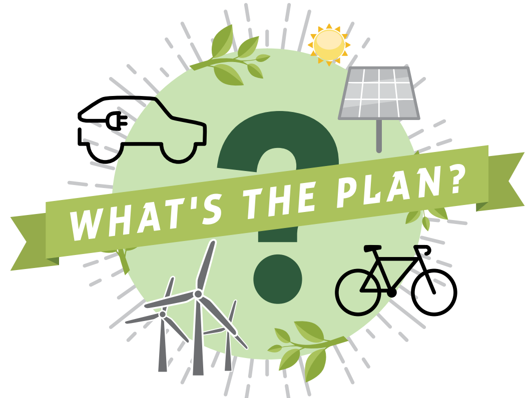
Image Credit: The Guardian (https://www.theguardian.com/environment/ng-interactive/2019/jul/19/carbon-calculator-how-taking-one-flight-emits-as-much-as-many-people-do-in-a-year)

1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

2. Borken-Kleefeld, J., Fuglestvedt, J. and T. Berntsen. 2013. Mode, load, and specific climate impact from passenger trips. Environ. Sci. Technol. 47: 7608–7614.

3. Airlines for America. 2016. Air travel is affordable, accessible, and vast majority of travelers satisfied with overall experience according to new national survey

MITIGATION STRATEGY: PLANT-BASED MEAT



People have relied on livestock, like cattle, as a food source for thousands of years. Many domestic animals are able to eat the plants that grow in dry environments, allowing people to live in places where they cannot grow many crops. However, raising cattle requires a lot of land, water and food. According to the United Nations (2013), livestock produce 14.5% of global greenhouse gas emissions. Many people suggest reducing the amount of meat you eat as a way to decrease greenhouse gas emissions. There are multiple companies that sell plant-based meat, a food designed to taste and look like meat but actually made from plants. These products, such as the Impossible Burger and Beyond Meat, require less land and water to produce, and making them releases less carbon dioxide and other greenhouse gasses into the atmosphere than raising livestock. Scientists have calculated that one person choosing a plant-based diet can save 0.82 metric tons of carbon per year.[1]

WHAT COULD HELP MAKE THIS HAPPEN:

- People choosing to eat plant-based meat over real meat.
- Companies continuing to develop better tasting and healthier plant-based meats.
- Scientists researching how to make healthy, environmentally friendly plant-based meats.
- Large restaurant chains could switch to plant-based meats. McDonalds, Burger King, KFC and Carl's Jr. have all added plant-based meats to their menus.

CHALLENGES:

- Thousands of people make a living through the meat industry: raising, feeding, slaughtering and selling livestock.
- Many people like to eat meat.
- Scientists are researching whether new plant-based meats are healthier than meat products.[2,3]
- Plant-based meat, especially burgers and chicken, is generally more expensive than real meat.[4]
- Many people rely on fast food, like hamburgers and chicken nuggets, that is inexpensive and easy to get.

That takes the brisket

2019 or latest available

		Greenhouse-gas emissions kg of CO_2 equivalent per kg	Freshwater withdrawals litres per kg	Land use m^2 per kg
Meat*	Beef (herd)	99.5	1,451	326
	Pork	12.3	1,796	7.8
	Chicken	9.9	660	6.7
Beyond Burger		3.5	9.7	2.7
Impossible Burger		3.5	107	2.5

Source: Ron Milo, Weizmann Institute and Alon Shepon, Harvard University *Global average, 1kg of fat and bone-free meat and edible offal

The Economist

Image Credit: The Economist (https://www.economist.com/international/2019/10/12/plant-based-meat-could-create-a-radically-different-food-chain)

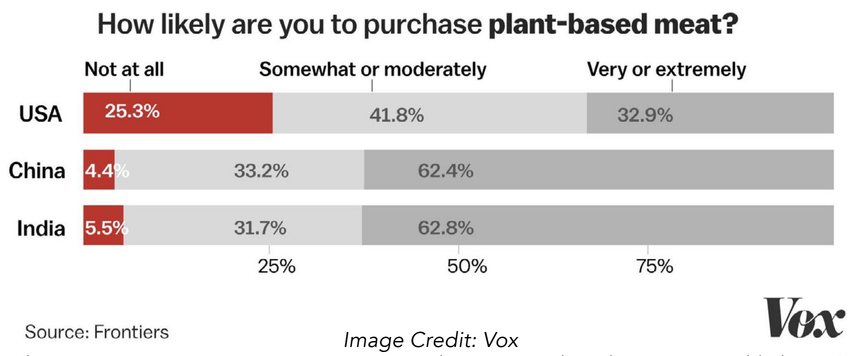
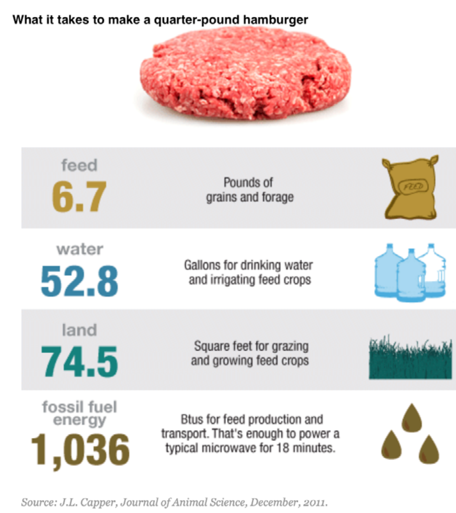


Image Credit: Vox (https://www.vox.com/2019/5/28/18626859/meatless-meat-explained-vegan-impossible-burger)



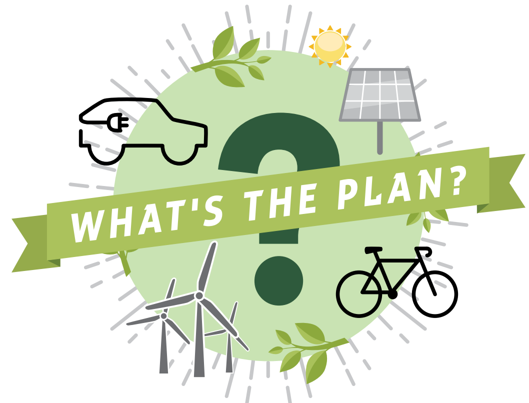
1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12

2. Plant-based meat lowers some cardiovascular risk factors compared with red meat, study finds/Journal of Clinical Nutrition

3. Harvard Health Publishing. 2019. Impossible and Beyond: How healthy are these meatless burgers?

4. Vox. 2020. The next challenge for plant-based meat: Winning the price war against animal meat

MITIGATION STRATEGY: LIVE CAR FREE



A typical passenger car emits 4.6 metric tons of carbon dioxide per year (EPA, 2018). It is estimated that there are currently over 1 billion vehicles in the world. Living without a car challenges people to find alternative transportation options like walking, biking, or taking trains and buses. People without a car tend to travel shorter distances in their daily lives. Fewer cars on the road means that the remaining drivers will waste less gas sitting in traffic, and infrastructure like roads and bridges will last longer and need less maintenance due to lighter use. Scientists have estimated that one person switching from an average car to a car-free life-style will save 2.4 metric tons of CO_2 per year.[1]

WHAT COULD HELP MAKE THIS HAPPEN:

- Investing in more public transportation, like buses and trains.
- Car, bike, and scooter sharing apps.
- Making cities more pedestrian and bike friendly.
- Building stores in residential areas so people can walk to them.
- More people working from home.
- Higher gasoline prices to make driving less affordable.

CHALLENGES:

- Easiest to do in cities where homes, stores, and work places are close together; hard to do in rural or suburban areas.
- Much of the country lacks efficient public transportation.
- It's hard to travel outside of your city or hometown without a car.
- There are many jobs that rely on car owners (sales, mechanics, car detailers, etc.).
- Not having a car limits how far you can go to find work, health care, and other necessities.

1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

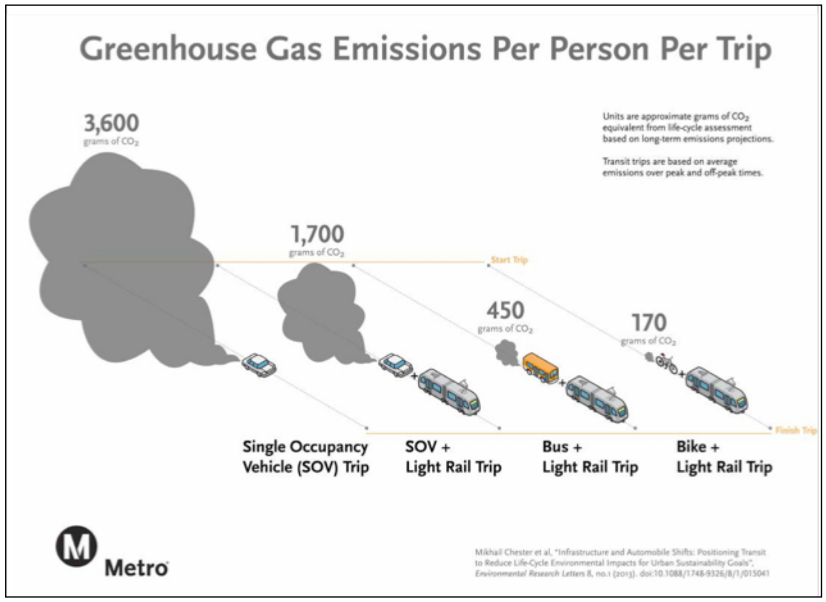


Image Credit: Metro
(https://thesource.metro.net/2017/03/20/seven-ways-riding-a-bike-can-improve-your-life/)

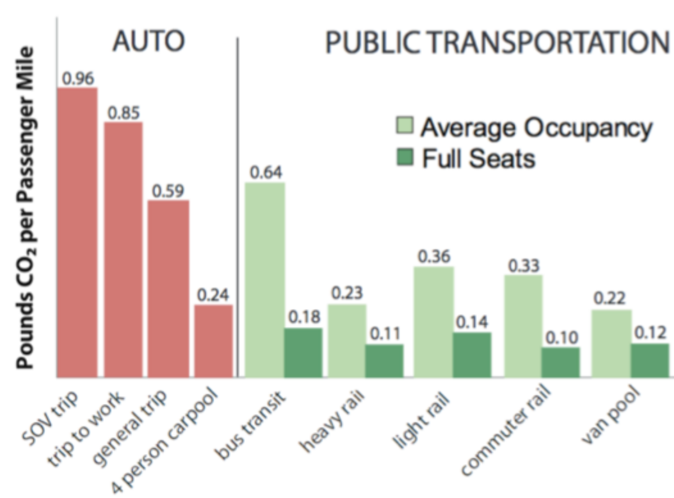
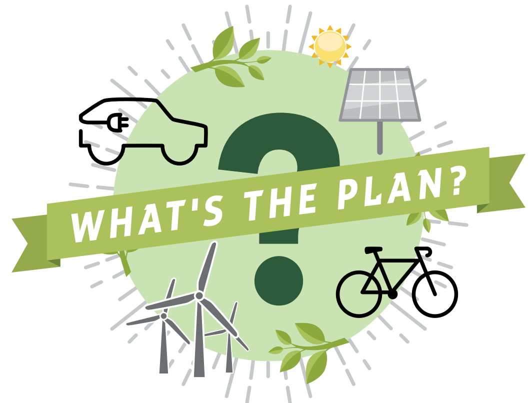


Figure 1.1: Comparison of pounds of CO2 per passenger mile for difference personal vehicle trips and different modes of public transportation, showing the potential of increased public transit use and reduced personal vehicle use could have on GHG emissions (US DOT, 2010).

Image Credit: Metro
(https://thesource.metro.net/2017/03/20/seven-ways-riding-a-bike-can-improve-your-life/)



MITIGATION STRATEGY: HAVE ONE FEWER CHILD

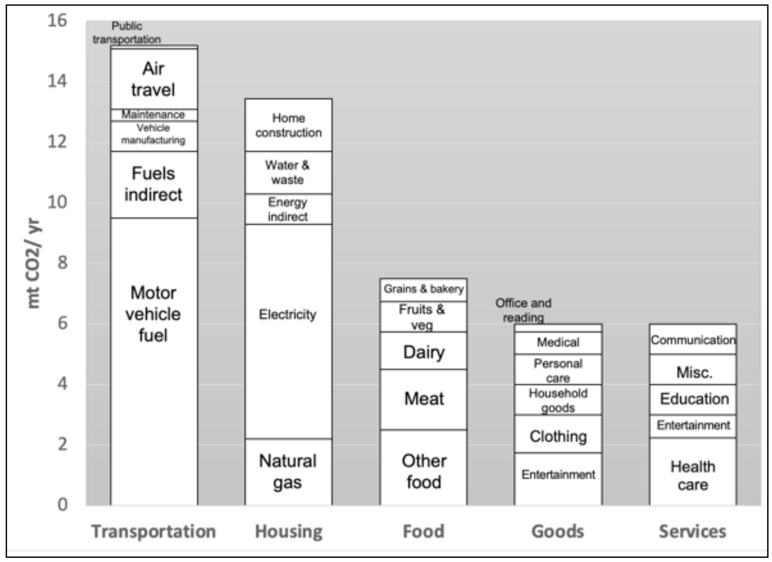
Population growth is often named one of the greatest environmental challenges. As the global population has grown, production of food, energy, and goods has increased to meet the needs of the population. This also leads to an increase in waste and pollution. By making the decision to have one fewer child, parents are decreasing their current carbon emissions and their carbon legacy, the future carbon emissions of their descendants. By slowing population growth, resource consumption and pollution emissions also slow down. Scientists have estimated that having one fewer child will save 58.6 metric tons of carbon over a lifetime.[1]

WHAT COULD HELP MAKE THIS HAPPEN:

- Educating people about the impacts of individuals on climate change.
- Research shows providing women with easy access to education and health care results in them having fewer children.[2]

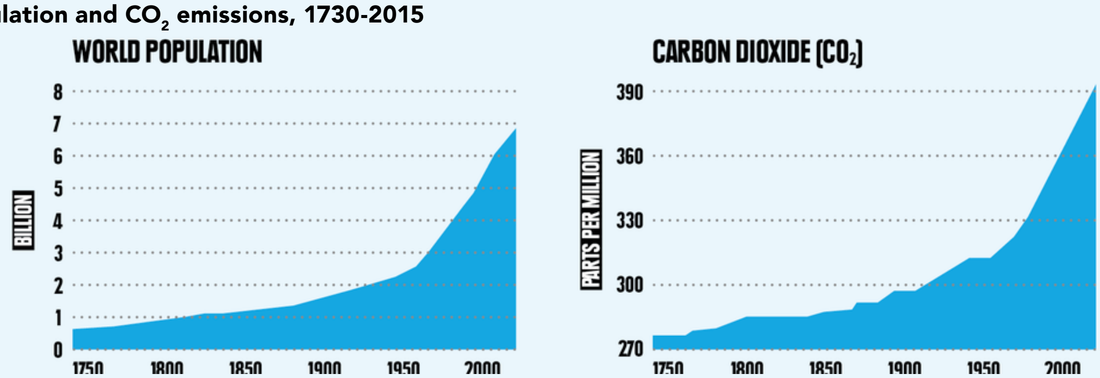
CHALLENGES:

- How do you enforce or encourage people to keep their family size small?
- Many people have a cultural or personal preference for large families.
- Many people have a cultural, religious, or personal belief against contraception.
- Is it a violation of human rights to enforce this?
- When the Chinese government set a one child rule, a preference for sons led to a gender imbalance and poor treatment of daughters.[3]
- Younger generations support older generations through social security, Medicaid, etc. When there are more older than younger people, there are fewer resources to support the elderly.



Total carbon emissions of a typical US household 48 tons (CO_2/year)
Jones, C. M., & D. M. Kammen 2011.Environmental Science & Technology.

Population and CO_2 emissions, 1730-2015



Source: United Nations, 2017

Image Credit: The Medium
(https://medium.com/altering-climate/population-control-the-most-effective-way-to-reduce-carbon-emissions-altering-climate-a6efe56db2b)

1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

2. Wodon, Q., C. Montenegro, H. Nguyen, and A. Onagoruwa. 2018, Missed Opportunities: The High Cost of Not Educating Girls. The Cost of Not Educating Girls Notes Series. Washington, DC: The World Bank.

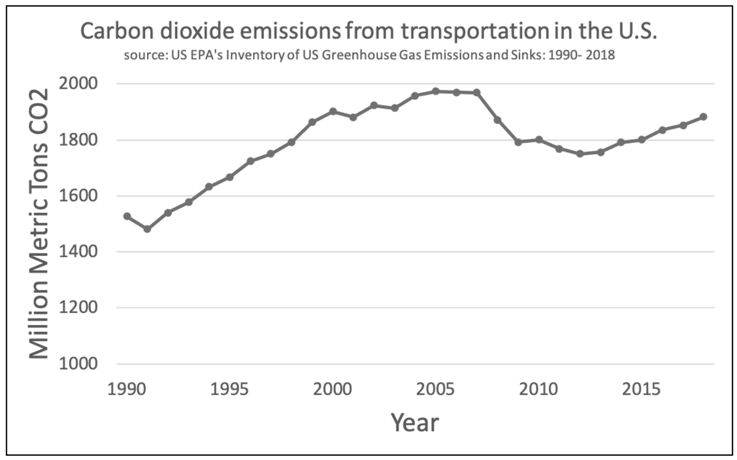
3. Johnson, Kay Ann (2016). China's hidden children: Abandonment, adoption, and the human costs of the one- child policy. Chicago: University of Chicago Press. 2016.

MITIGATION STRATEGY: FUEL EFFICIENT CARS

The fuel efficiency of an average car is 30 miles per gallon (mpg), but the popular hybrid car below is estimated to achieve up to 58 mpg. A typical passenger car emits 4.6 metric tons of carbon dioxide per year (EPA, 2018). It is estimated that there are currently over 1 billion vehicles in the world, and there will be 2 billion by 2035. Owners of hybrid cars usually spend less on gas because the car is more efficient, but hybrid cars usually cost more than average cars, making it hard for some to afford them. Scientists have calculated that carbon emissions would be reduced by 1 Pg/year if we replaced 2 billion average cars with fuel efficient cars.[1] One person can reduce their carbon emissions by 0.52 metric tons of carbon per year by switching from a traditional to hybrid car.[2]

WHAT COULD HELP MAKE THIS HAPPEN:

- Governments could offer a tax credit to offset the cost of the car.
- A new law could require new cars to be more fuel efficient.
- Allow fuel efficient cars to use the carpool or HOV lanes to avoid traffic.

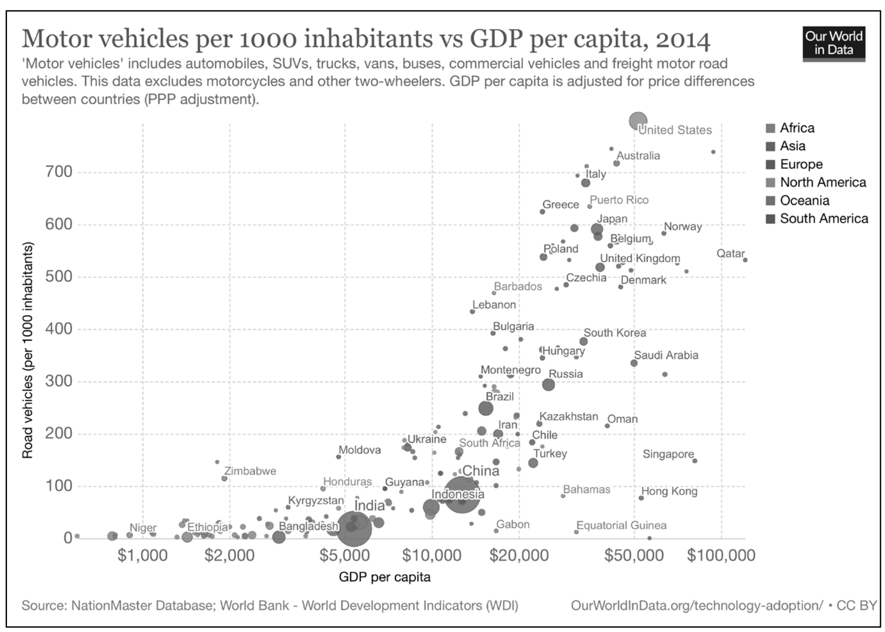


CHALLENGES:

- Hybrid and electric cars are more expensive.
- Fuel efficient cars are usually smaller and less powerful than standard cars.
- Car manufacturing plants are set up to make standard cars; making new types of cars requires them to change their factory set up and equipment.

Photo credit: Toyota (toyota.com/search/search.html?keyword=prius)

Image credit (right): Our World in Data (https://ourworldindata.org/grapher/road-vehicles-per-1000-inhabitants-vs-gdp-per-capita?time=latest&country=USA~BRB)



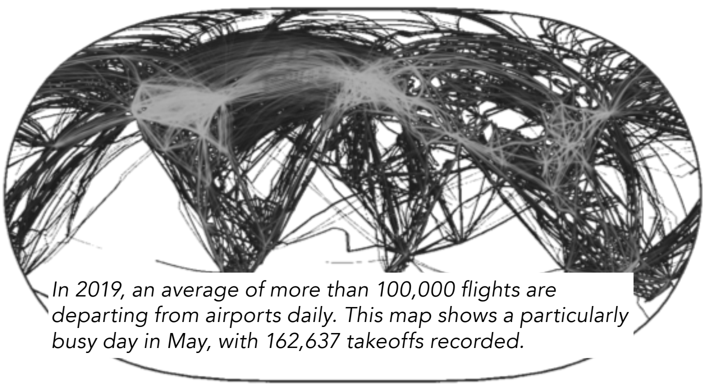
1. Pacala, S. and R. Socolow. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 305: 968-972.

2. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

3. Environmental Protection Agency. 2020. Inventory of US Greenhouse Gas Emissions and Sinks 1990-2018

MITIGATION STRATEGY: DECREASE AIR TRAVEL

Traveling by airplane emits large amounts of carbon into the atmosphere due to burning fuel. The United Nations (2019) predicts CO_2 emissions from air travel could triple by 2050. A round trip from New York to San Francisco generates approximately 1 metric ton of CO_2 per passenger. Eliminating or minimizing air travel is often claimed to be one of the most effective ways an individual can decrease their carbon emissions. Compared to traveling by car, the greenhouse gas emissions per passenger traveling by plane are much higher, especially for shorter distances. A family of four driving from Los Angeles to San Francisco generates about a third of the CO_2 that flying would generate. According to a NASA (2010) study, most of the emissions generated by planes are from take off and landing. Scientists have calculated that avoiding one transatlantic flight per year will save 1.6 metric tons of CO_2,[1] or decrease the average American's carbon emissions by 10%.



In 2019, an average of more than 100,000 flights are departing from airports daily. This map shows a particularly busy day in May, with 162,637 takeoffs recorded.

Image Credit: The Guardian (https://www.theguardian.com/environment/ng-interactive/2019/jul/19/carbon-calculator-how-taking-one-flight-emits-as-much-as-many-people-do-in-a-year)

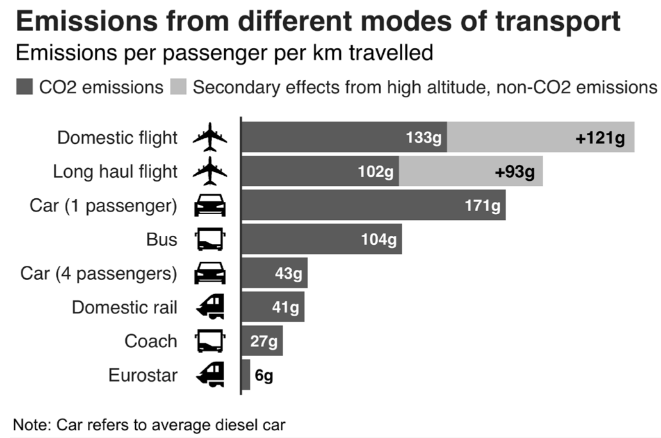


Image Credit: BBC (https://www.bbc.com/news/science-environment-49349566)

WHAT COULD HELP MAKE THIS HAPPEN:

- Normalizing telework and work-from-home so traveling for business becomes less necessary.
- Using alternate methods of travel – more long distance and fast buses and trains.
- Choosing nonstop flights to decrease the number of take offs and landings during a trip.
- Educate people about the carbon costs of travel (e.g. an app that tells you how much carbon a trip releases).
- Purchase carbon offsets if flights are required.
- Discourage private jet flights.

CHALLENGES:

- 30% of American air travel is business-related travel, not personal choices.[3]
- When there is only one person in the car, carbon emissions from a long road trip are actually higher than from flying.[2]
- Flying is convenient and fast.
- There are not easy alternatives to flying (e.g., high speed trains) in the U.S.

Flying from Los Angeles (LAX) to New York John F. Kennedy (JFK)

Flying from Los Angeles to New York John F. Kennedy and back generates about 697 kg CO_2. There are 50 countries where the average person produces less CO_2 in a year.

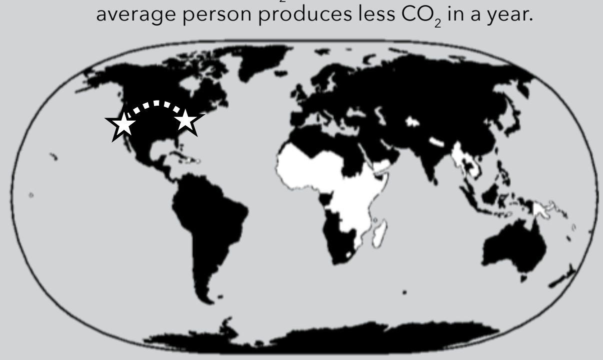


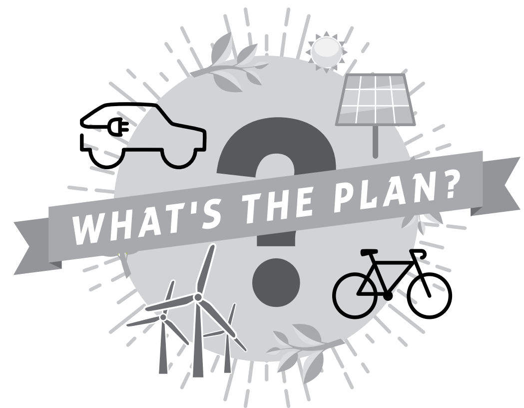
Image Credit: The Guardian (https://www.theguardian.com/environment/ng-interactive/2019/jul/19/carbon-calculator-how-taking-one-flight-emits-as-much-as-many-people-do-in-a-year)

1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

2. Borken-Kleefeld, J., Fuglestvedt, J. and T. Berntsen. 2013. Mode, load, and specific climate impact from passenger trips. Environ. Sci. Technol. 47: 7608–7614.

3. Airlines for America. 2016. Air travel is affordable, accessible, and vast majority of travelers satisfied with overall experience according to new national survey

MITIGATION STRATEGY: PLANT-BASED MEAT



People have relied on livestock, like cattle, as a food source for thousands of years. Many domestic animals are able to eat the plants that grow in dry environments, allowing people to live in places where they cannot grow many crops. However, raising cattle requires a lot of land, water and food. According to the United Nations (2013), livestock produce 14.5% of global greenhouse gas emissions. Many people suggest reducing the amount of meat you eat as a way to decrease greenhouse gas emissions. There are multiple companies that sell plant-based meat, a food designed to taste and look like meat but actually made from plants. These products, such as the Impossible Burger and Beyond Meat, require less land and water to produce, and making them releases less carbon dioxide and other greenhouse gasses into the atmosphere than raising livestock. Scientists have calculated that one person choosing a plant-based diet can save 0.82 metric tons of carbon per year.[1]

WHAT COULD HELP MAKE THIS HAPPEN:

- People choosing to eat plant-based meat over real meat.
- Companies continuing to develop better tasting and healthier plant-based meats.
- Scientists researching how to make healthy, environmentally friendly plant-based meats.
- Large restaurant chains could switch to plant-based meats. McDonalds, Burger King, KFC and Carl's Jr. have all added plant-based meats to their menus.

CHALLENGES:

- Thousands of people make a living through the meat industry: raising, feeding, slaughtering and selling livestock.
- Many people like to eat meat.
- Scientists are researching whether new plant-based meats are healthier than meat products.[2,3]
- Plant-based meat, especially burgers and chicken, is generally more expensive than real meat.[4]
- Many people rely on fast food, like hamburgers and chicken nuggets, that is inexpensive and easy to get.

That takes the brisket
2019 or latest available

		Greenhouse-gas emissions kg of CO_2 equivalent per kg	Freshwater withdrawals litres per kg	Land use m^2 per kg
Meat*	Beef (herd)	99.5	1,451	326
	Pork	12.3	1,796	7.8
	Chicken	9.9	660	6.7
Beyond Burger		3.5	9.7	2.7
Impossible Burger		3.5	107	2.5

Source: Ron Milo, Weizmann Institute and Alon Shepon, Harvard University *Global average, 1kg of fat and bone-free meat and edible offal

The Economist

Image Credit: The Economist (https://www.economist.com/international/2019/10/12/plant-based-meat-could-create-a-radically-different-food-chain)

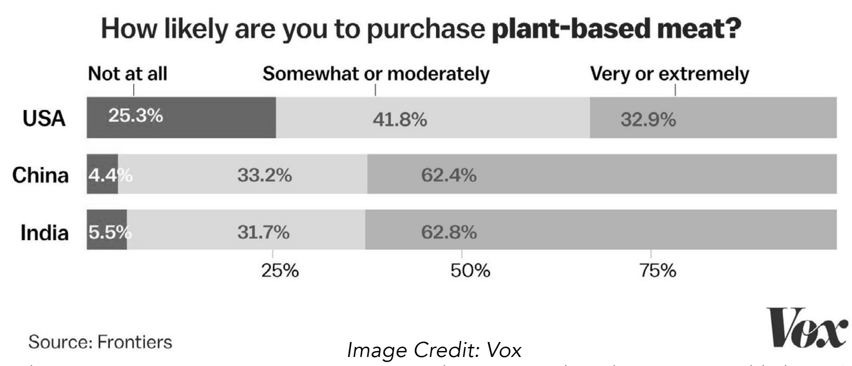
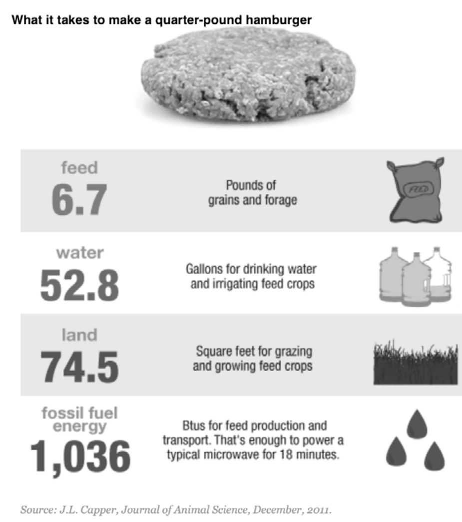


Image Credit: Vox (https://www.vox.com/2019/5/28/18626859/meatless-meat-explained-vegan-impossible-burger)



1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12

2. Plant-based meat lowers some cardiovascular risk factors compared with red meat, study finds/Journal of Clinical Nutrition

3. Harvard Health Publishing. 2019. Impossible and Beyond: How healthy are these meatless burgers?

4. Vox. 2020. The next challenge for plant-based meat: Winning the price war against animal meat

MITIGATION STRATEGY: LIVE CAR FREE

A typical passenger car emits 4.6 metric tons of carbon dioxide per year (EPA, 2018). It is estimated that there are currently over 1 billion vehicles in the world. Living without a car challenges people to find alternative transportation options like walking, biking, or taking trains and buses. People without a car tend to travel shorter distances in their daily lives. Fewer cars on the road means that the remaining drivers will waste less gas sitting in traffic, and infrastructure like roads and bridges will last longer and need less maintenance due to lighter use. Scientists have estimated that one person switching from an average car to a car-free life-style will save 2.4 metric tons of CO_2 per year.[1]

WHAT COULD HELP MAKE THIS HAPPEN:

- Investing in more public transportation, like buses and trains.
- Car, bike, and scooter sharing apps.
- Making cities more pedestrian and bike friendly.
- Building stores in residential areas so people can walk to them.
- More people working from home.
- Higher gasoline prices to make driving less affordable.

CHALLENGES:

- Easiest to do in cities where homes, stores, and work places are close together; hard to do in rural or suburban areas.
- Much of the country lacks efficient public transportation.
- It's hard to travel outside of your city or hometown without a car.
- There are many jobs that rely on car owners (sales, mechanics, car detailers, etc.).
- Not having a car limits how far you can go to find work, health care, and other necessities.

1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

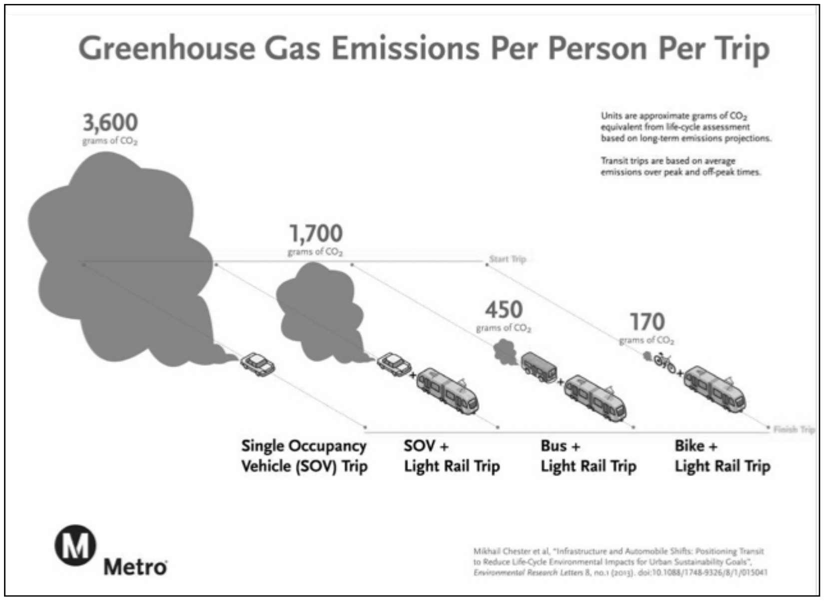


Image Credit: Metro
(https://thesource.metro.net/2017/03/20/seven-ways-riding-a-bike-can-improve-your-life/)

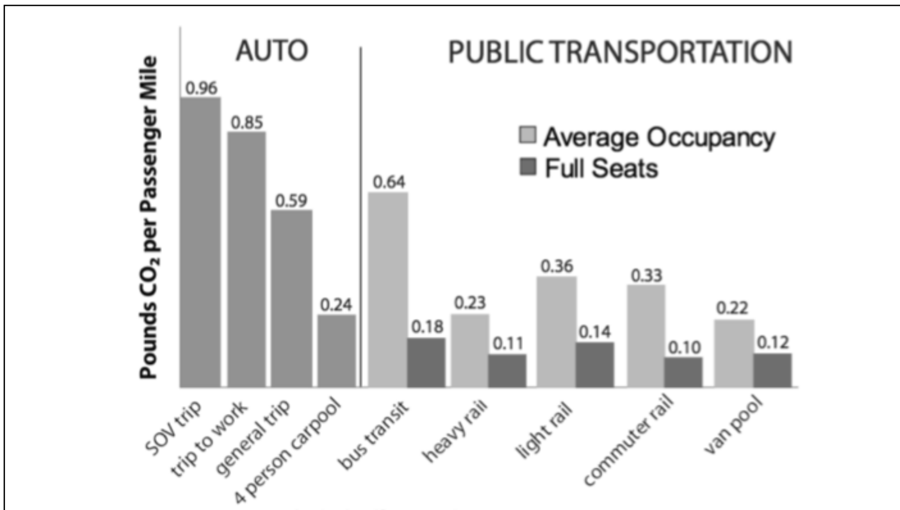


Figure 1.1: Comparison of pounds of CO2 per passenger mile for difference personal vehicle trips and different modes of public transportation, showing the potential of increased public transit use and reduced personal vehicle use could have on GHG emissions (US DOT, 2010).

Image Credit: Metro
(https://thesource.metro.net/2017/03/20/seven-ways-riding-a-bike-can-improve-your-life/)

MITIGATION STRATEGY: HAVE ONE FEWER CHILD

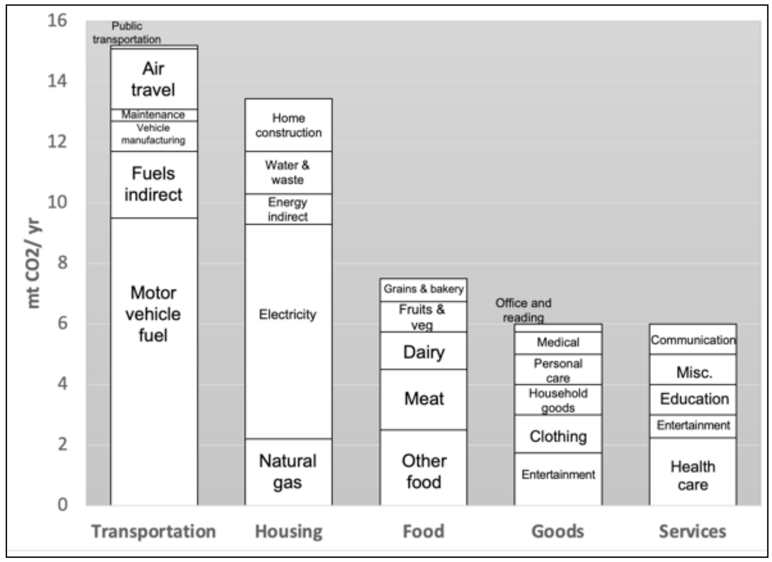
Population growth is often named one of the greatest environmental challenges. As the global population has grown, production of food, energy, and goods has increased to meet the needs of the population. This also leads to an increase in waste and pollution. By making the decision to have one fewer child, parents are decreasing their current carbon emissions and their carbon legacy, the future carbon emissions of their descendants. By slowing population growth, resource consumption and pollution emissions also slow down. Scientists have estimated that having one fewer child will save 58.6 metric tons of carbon over a lifetime.[1]

WHAT COULD HELP MAKE THIS HAPPEN:

- Educating people about the impacts of individuals on climate change.
- Research shows providing women with easy access to education and health care results in them having fewer children.[2]

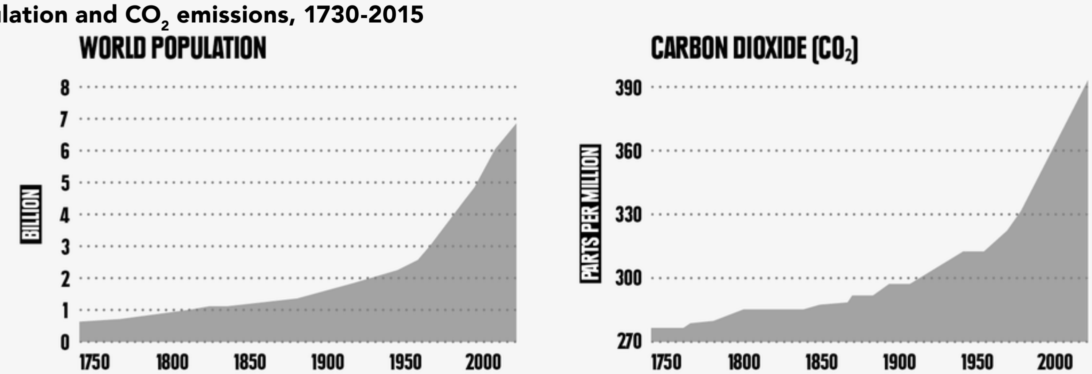
CHALLENGES:

- How do you enforce or encourage people to keep their family size small?
- Many people have a cultural or personal preference for large families.
- Many people have a cultural, religious, or personal belief against contraception.
- Is it a violation of human rights to enforce this?
- When the Chinese government set a one child rule, a preference for sons led to a gender imbalance and poor treatment of daughters.[3]
- Younger generations support older generations through social security, Medicaid, etc. When there are more older than younger people, there are fewer resources to support the elderly.



Total carbon emissions of a typical US household 48 tons (CO_2/year)
Jones, C. M., & D. M. Kammen 2011.Environmental Science & Technology.

Population and CO_2 emissions, 1730-2015



Source: United Nations, 2017

Image Credit: The Medium
(https://medium.com/altering-climate/population-control-the-most-effective-way-to-reduce-carbon-emissions-altering-climate-a6efe56db2b)

1. Wynes, S. and Nicholas, K.A. 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters: 12.

2. Wodon, Q., C. Montenegro, H. Nguyen, and A. Onagoruwa. 2018, Missed Opportunities: The High Cost of Not Educating Girls. The Cost of Not Educating Girls Notes Series. Washington, DC: The World Bank.

3. Johnson, Kay Ann (2016). China's hidden children: Abandonment, adoption, and the human costs of the one- child policy. Chicago: University of Chicago Press. 2016.

Names: ____________________

____

____

CLIMATE CHANGE M

STRATEGY: ____________________

1. Who will be involved in this strategy?
Think of 3-5 people or groups who would have an opinion about this strategy. Would they be for or against it?

2. Who will be in charge of making this strategy happen?

3. Where will this happen?
What does the ideal place for this to happen look like? Is there anywhere this wouldn't work?

4. What are the biggest challenges t strategy? How will you address th

7. Explain how you will implement t strategy. How can you address th arguments against the strategy?

HANGE MITIGATION

st challenges to implementing this
ou address these challenges?

l implement this mitigation
ou address the challenges and
he strategy?

5. Arguments for this strategy:
How could this help individuals, communities, and the planet?

1.

2.

3.

4.

6. Arguments against this strategy:
How could this harm individuals, communities, and the planet?

1.

2.

3.

4.

STAKEHOLDER CARDS

Stakeholder: Solar Engineer

You are an engineer who works for a company that builds and installs solar panels. The more solar panels in the world, the more demand there will be for your skills.

Stakeholder: Coal Miner

You live in a small town where people have been mining coal for 100 years. Most people you know work for a coal company. There isn't an endless supply of coal in the ground, so you worry about what would happen if the mine closed.

Stakeholder: Homeowner

You just bought a house and are interested in buying solar panels. You are worried that it is too expensive to buy solar panels.

Stakeholder: Homeowner

You just bought a house, and you want to install solar panels. You like that it will help slow climate change and that you won't have to pay electricity bills anymore. Your regular electricity bill is about $100 per month, and solar panels cost about $14,000 to install.

Stakeholder: Government Official

You work for the department of energy, and your job is to think about the big picture of energy resources in the country. You wonder where people will get their energy in 50 years and how can we prepare for that future now?

Stakeholder: Apartment Renter

You live in an apartment building with many other people. Your apartment doesn't have the space to install enough solar panels to meet the needs of your entire building.

Stakeholder: Environmentalist

You spend a lot of your time volunteering with groups that help protect the environment, and you are very concerned about climate change and greenhouse gasses. You think that replacing coal power plants with solar panels is a big part of the solution, but you aren't sure how to convince other people this is important.

Stakeholder: Power Company

You run a power company that provides electricity to millions of homes. Most of the electricity comes from coal-burning power plants, but the company also has some solar panels and wind turbines. You know that coal is getting more expensive and that there will probably be laws that limit the emission of greenhouse gasses in the future. You are concerned with making sure your company continues to provide electricity to customers.

Stakeholder: Lobbyist

You work for an organization with a lot of money and clients who want to decrease regulations on fossil fuel companies.

Stakeholder: Lobbyist

You work for an organization with a lot of money and clients who want to increase regulations on fossil fuel companies.

Stakeholder: Landowner

You own a big piece of land right outside a city, and a solar energy company has approached you and wants to rent your land to build solar panels.

Stakeholder: Charitable Organization Worker

You work for an organization that provides solar energy to developing countries. You recognize the importance of renewable energy for the future. However, from your experience, you've seen that developing countries cannot invest in the necessary technology.

Stakeholder: Meteorologist

You are a weather expert in Seattle, Washington. You know that there is an average of 152 sunny days per year where you live. Your friend wants to put solar panels on their roof. They asked you if you think it's a good idea and if it will generate much energy.

Stakeholder: Meteorologist

You are a weather expert in Phoenix, Arizona. You know that there is an average of 299 sunny days per year where you live. Your friend wants to put solar panels on their roof. They asked you if you think it's a good idea and if it will generate much energy.

Stakeholder: Coal Miner

You live in a small town where people have been mining coal for 100 years. Most people you know work for a coal company. More solar energy will mean less demand for coal. You worry that you and most of the people you know could lose jobs.

Stakeholder: Doctor

You are a doctor in a city where a lot of people have asthma. You know that clean air helps your patients, and you know that more renewable energy would decrease air pollution.

Stakeholder: Solar Company Owner

You own a company that makes solar panels. If more people used solar energy, your company would be able to expand, and you would hire more workers with the increased profits.

Stakeholder: Construction Worker

California has a new law that requires all new homes to have solar panels. You worry that this will make homes more expensive, and you don't yet have the expertise needed to install solar panels.

STAKEHOLDER CARDS

Stakeholder: Wildlife Biologist

You study the dune sagebrush lizard, a unique and endangered species that lives only in New Mexico. Its habitat is being destroyed by fossil fuel companies mining for oil and gas. You think that reducing the use of fossil fuels will protect this species.

Stakeholder: Wildlife Biologist

You study wildlife in southern New Mexico. Because fossil fuel mining harms some rare species, the fossil fuel companies have agreed to provide money and support for wildlife conservation that benefits many species you study.

Stakeholder: Economist

You know that if we switch to solar energy, in the long run, it will be less expensive than fossil fuels, which could be good for the future economy.

Stakeholder: Economist

You know that there are thousands of jobs that depend on the fossil fuel industry, and if those jobs suddenly disappear, many people will suffer financially.

Stakeholder: Water Quality Expert

You know that water will be cleaner in the long-term if we switch to solar energy due to less air and water pollution.

Stakeholder: Politician

You were elected to your state government because you promised to help represent the people's voice in the government. You know that people want jobs and resources available for a bright future in your community. What does your community think about solar energy?

CLIMATE CHANGE AND THE CARBON CYCLE

COMMON CORE STATE STANDARDS ACTIVITY CHARTS

This chart identifies the Climate Change and the Carbon Cycle activities that apply to each of the listed Common Core State Standards. Some standards are fully met by the activities, and some standards are addressed by the activities but require further teaching.

ENGLISH LANGUAGE ARTS			
	Up in the Air	**The Ins and Outs of a Climate Feedback Loop**	**What's the Plan? Climate Change Mitigation**
CCSS.ELA-LITERACY.W.9-10.1.E.	●	●	
CCSS.ELA-LITERACY.RST.9-10.3.	●	●	
CCSS.ELA-LITERACY.RST.9-10.4.	●	●	
CCSS.ELA-LITERACY.RST.9-10.7.	●		
CCSS.ELA-LITERACY.RI.9-10.8.			●
CCSS.ELA-LITERACY.RI.11-12.7.			●
CCSS.ELA-LITERACY.W.9-12.1.			●
CCSS.ELA-LITERACY.W.9-12.2.			●
MATHEMATICS			
CCSS.MATH.CONTENT.HSN.Q.A.1.	●		
CCSS.MATH.CONTENT.HSN.Q.A.2.	●	●	
CCSS.MATH.CONTENT.HSS.ID.A.2.		●	

CLIMATE CHANGE AND THE CARBON CYCLE

NEXT GENERATION SCIENCE STANDARDS ACTIVITY CHARTS

Performance Expectations
This chart identifies the Climate Change and the Carbon Cycle activities that address each of the listed Next Generation Science Standards Performance Expectations.

NGSS PERFORMANCE EXPECTATIONS			
	Up in the Air	**The Ins and Outs of a Climate Feedback Loop**	**What's the Plan? Climate Change Mitigation**
HS-ESS2-2		●	
HS-ESS2-6	●		
HS-ESS3-4			●

Three Dimensions
This chart identifies the Climate Change and the Carbon Cycle activities that address each of the listed three dimensions of the Next Generation Science Standards.

NGSS THREE DIMENSIONS			
	Up in the Air	**The Ins and Outs of a Climate Feedback Loop**	**What's the Plan? Climate Change Mitigation**
SCIENCE AND ENGINEERING PRACTICES			
Developing and Using Models	●	●	
Analyzing and Interpreting Data		●	
Constructing Explanations and Designing Solutions			●
DISCIPLINARY CORE IDEAS			
ESS2.A: Earth Materials and Systems		●	
ESS2.D: Weather and Climate	●	●	
ESS3.C Human Impacts on Earth Systems	●		●
ESS3.D Global Climate Change	●		●
ETS1.B Developing Possible Solutions			●
CROSSCUTTING CONCEPTS			
Scale, Proportion, and Quantity	●		
Energy and Matter	●		
Systems and System Models		●	
Stability and Change		●	●