

Carbon & the Carbon Cycle: Why is everyone talking about it?

Synopsis of the Activity

Learners use information from carbon cycle reservoir and flow cards as well as a carbon cycle game and an interactive computer carbon cycle diagram to build understanding of how carbon flows between reservoirs on Earth, with and without human industry.

Audience

This activity is designed for the general public and is best accessed by learners in middle school or older. It is best done with small groups of visitors.

Key Concepts:

- Carbon moves between reservoirs, but the total amount of carbon on Earth doesn't change.
- Human industry moves carbon out of fossil fuel and limestone reservoirs and into the atmosphere.

Other Ideas Addressed:

- Fossil fuels and many other things produce CO₂ when they combust.
- Natural flows move small amounts of carbon out of the reservoirs of fossil fuels and limestone.
- One carbon atom may move through many different reservoirs.
- Every scientific model has ways in which it is accurate and ways in which it is inaccurate.

Climate Literacy Principles:

2. Climate is regulated by complex interactions among components of the Earth system.
 - d. The abundance of greenhouse gases in the atmosphere is controlled by biogeochemical cycles that continually move these components between their ocean, land, life, and atmosphere reservoirs. The abundance of carbon in the atmosphere is reduced through seafloor accumulation of marine sediments and accumulation of plant biomass and is increased through deforestation and the burning of fossil fuels as well as through other processes.
4. Climate varies over space and time through both natural and man-made processes.
 - g. Natural processes that remove carbon dioxide from the atmosphere operate slowly when compared to the processes that are now adding it to the atmosphere. Thus, carbon dioxide introduced into the atmosphere today may remain there for a century or more. Other greenhouse gases, including some created by humans, may remain in the atmosphere for thousands of years.
6. Human activities are impacting the climate system.
 - c. Human activities have affected the land, oceans, and atmosphere, and these changes have altered global climate patterns. Burning fossil fuels, releasing chemicals into the atmosphere, reducing the amount of forest cover, and rapid expansion of farming, development, and industrial activities are releasing carbon dioxide into the atmosphere and changing the balance of the climate system.

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Ocean Literacy Principles:

2. The ocean and life in the ocean shape the features of Earth.

d The ocean is the largest reservoir of rapidly cycling carbon on Earth. Many organisms use carbon dissolved in the ocean to form shells, other skeletal parts, and coral reefs.

3. The ocean is a major influence on weather and climate.

e. The ocean dominates Earth's carbon cycle. Half of the primary productivity on Earth takes place in the sunlit layers of the ocean. The ocean absorbs roughly half of all carbon dioxide and methane that are added to the atmosphere.

5. The ocean supports a great diversity of life and ecosystems.

b. Most of the organisms and biomass in the ocean are microbes, which are the basis of all ocean food webs. Microbes are the most important primary producers in the ocean. They have extremely fast growth rates and life cycles, and produce a huge amount of the carbon and oxygen on Earth.

Materials:

- Station sign that reads: *Carbon: Why is everyone talking about it?*
- Carbon cycle cards (reservoir (blue border) and flow cards (green border))
- Carbon Cards (orange border)
- Computer
- Carbon cycle diagram
- Different colored pencils – two colors per learner
- 2 sets of 10 each of 5 different colors of paper clips (green, red, blue, yellow, white)= total of 50 paperclips (one set for Model #1 and the second for Model #2)
- carbon cycle game boards (2 sets of each)
- dice (1 die per set)
- Keeling curve sheet
- “How much is a gigaton?” sheet
- Fossil fuel graph
- Focus questions sheet
- Key concepts sheet
- interactive carbon cycle diagram, computer model url:
 - <http://mare.lawrencehallofscience.org/curriculum/ocean-science-sequence/oss68-overview/oss68-resources/unit2>
 - Scroll down to *Session 2.7: Investigating Combustion and the Carbon Cycle*; then click on *Simulation: Interactive Carbon Cycle Diagram*.

Doing the Activity:

Invite learners to participate.

1. **Introduce topic.** When learners approach the station, greet them and let them know that you are exploring carbon and what is causing it to increase in the atmosphere. Ask about their prior knowledge with the following prompts and accept all responses
 - a. **What have you heard about the causes of climate change?"**
 - b. **"Lots of people talk about carbon when they talk about climate change. What have you heard about carbon and climate change?"**
2. **Summarize and introduce activity.** Depending on what the learners know about carbon in the atmosphere, share some of the following:
 - a. If they are not too familiar with carbon in the atmosphere
 - Ask them if they are interested in learning a bit about why everyone keeps talking about carbon when they talk about climate change.
 - Share that scientists have determined that the major cause of climate change is due to human activities adding increasing carbon (in the form of carbon dioxide gas) into the atmosphere.
 - b. If the learner knows quite a bit, ask if they are interested in learning more through some models and games.

Exploring how carbon moves between reservoirs.

1. **Introduce carbon reservoirs images.** Show the colored images of five reservoirs (animal, plant, fossil fuel, ocean and atmosphere). Define reservoirs as places that store carbon. Facilitate a discussion about the images and where carbon is found in each. Explain that each is a carbon reservoir.
 - a. **Carbon cards.** Distribute the carbon cards and have learners explore other examples of carbon reservoirs and look for the form that the carbon can be found in each (e.g. $C_6H_{12}O_6$ in plants).
 - b. Ask, **"Which of these places have you heard about before? Which of these carbon reservoirs do you find interesting or surprising? What questions do you have about these carbon reservoirs?"** Accept all responses and share answers to questions as appropriate.
 - c. After exploring, collect the cards and move them out of the way.
2. **Introduce Challenge – follow the carbon.** Tell learners that their challenge for this activity is to follow the carbon from one reservoir to another and to describe how carbon might move between the reservoirs. Have learners look at the images of the atmosphere and the tree and ask them if they could try to explain how carbon might move between these two reservoirs. Have them discuss this question with each other and then ask a volunteer to share ideas they discussed. If they don't know, describe photosynthesis and respiration very briefly as a way to provide an example of carbon (as CO_2) moving (or flowing) between reservoirs.

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- 3. Carbon Cycle Cards – facilitate discussions to gather information on how carbon moves between reservoirs.** Have learners choose another couple of reservoirs from the images and try to predict how carbon might flow between them. Challenge them to make some predictions. After a minute or so and depending on their prior knowledge, tell them that you have some cards that they can look through to find additional information. Share some of the carbon cycle reservoir (blue border) and flow cards (green border) for learners to examine for a few minutes as they show interest. Collect the cards and set aside for now.
- 4. Carbon cycle diagram – make predictions and record what you learned.** Distribute a carbon cycle diagram to each learner and a colored pencil. Challenge them to 1) label all the reservoirs they see, and 2) predict how carbon might flow between the reservoirs by drawing and labeling arrows to show the movement. Give them a few minutes to work on this and then you can have them share their drawings with each other. Also have them record anything they are wondering about.
- 5. Record moves with different color.** Tell them that they will next play a game that shows how carbon might move between these reservoirs. As they play the game, they will keep track of how they move the carbon between the reservoirs by adding arrows and labels to their own carbon cycle diagram using a different color pencil. Distribute a different color of pencil to each learner so they can record their moves.

Paper Clip Model #1

1. Introduce Paper Clip Carbon Cycle Model. Tell learners that we'll be using a game model of the carbon cycle that will allow us to follow carbon atoms as they move or flow through and get stored in many different places on Earth. Remind learners that a place that stores carbon is called a reservoir.

2. Demonstrate the model. Share Paper Clip Carbon Cycle Model #1. Point out that this model has only five carbon reservoirs, far less than the number of reservoirs we just saw in the carbon cards. The reservoirs are represented by the ovals on the page. The arrows between the reservoirs represent flows—how carbon moves from one reservoir to another, just like they showed on their own carbon cycle diagram. Show a couple of carbon cycle flow cards, especially the photosynthesis card, to clarify what you mean by flow and how carbon might move between reservoirs. Carbon atoms that belong to each reservoir are represented by different-colored paper clips, ten of each. All the paperclips represent identical carbon atoms—the different colors are so learners can remember which reservoir each carbon atom started in.

a. Set up. Show the learners how they should place ten paper clips in each reservoir oval on the model sheet. The sheet tells which color goes with which reservoir.

b. Demonstrate running the model. Say, **“Start with the ocean reservoir. One group member will roll a die. The number that comes up on the die will tell you where to move ONE carbon atom (paper clip) from that reservoir.”** Demonstrate by rolling the die, then locate the number shown on the die, and match it to one of the flow arrows that exits the ocean reservoir. Move one paper clip as indicated, but note that sometimes atoms don't actually leave the reservoir. Say, **“Each person will get one turn with the ocean reservoir, and then you**

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will move clockwise to the next reservoir where each person gets another turn. Continue until you've visited all five reservoirs."

3. Introduce focus questions for the game. Show the sheet of focus questions, and tell learners to keep these in mind as they observe what happens in their model. Leave the questions visible as learners work through the game.

4. Learners set up and run the model. Pass each group of 4-5 people a Paper Clip Carbon Cycle Model #1 sheet, a bag with the different colors of paper clips, and a die. Have groups set up their models and begin the cycle. Check in with each group (if there is more than one) to make sure they are running the model correctly. If a group is running it incorrectly, don't have them reset all the paper clips; have them run it correctly from that point forward.

Note to facilitator: The goal for using this model is to help the learners see the way in which carbon moves around Earth as a system. Learners should realize that even though the amount of carbon in one reservoir may increase or decrease, the total amount of carbon on Earth does not change. Using different colors of paper clips also allows students to observe that a carbon atom can move through many reservoirs.

5. Discuss focus questions with all learners. After groups run the models for about five minutes, have them set aside their materials. Discuss each of the focus questions. Ask,

- **"Which reservoirs increase? Which decrease?" "What is your evidence?"**
- **"Which reservoir gained the most atoms from different reservoirs?" "Do others agree or disagree?" "Why?"**
- **"What happens to the total number of carbon atoms on Earth?"** [Stays the same, even if some reservoirs increase or decrease.]

Paper Clip Model #2

1. Discuss increasing use of fossil fuels. Show the fossil fuels graph. Tell the learners that this rather complicated graph shows the increase in the combustion (burning) of various kinds of fossil fuels over the past 200 years. Let all of the learners describe what they notice. [People are using more and more fossil fuels every year. In the 1800s, they primarily used coal; since about 1950, the use of all fossil fuels has increased rapidly.]

2. Groups run Model #2 with new fossil fuels flows. Say, **"We will use our paper clip model to investigate how this increased combustion of fossil fuels might affect the carbon cycle."** Pass each group a Paper Clip Carbon Cycle Model #2 sheet, and an additional bag of paperclips. Tell them they can leave the Model #1 sheets as they are so that they can compare the results of the two models. Point out that the new model sheet has a combustion flow from the fossil fuels reservoir. Ask, **"Do you think the results from Model #2 will be the same or different from Model #1? Why?"** Accept all responses. Ask if others agree or disagree with ideas being expressed. Have learners set up and run the model with this sheet.

3. Discuss results. Allow all learners to share their results from Model #2. [More carbon atoms that were originally from fossil fuels are likely to end up in the atmosphere.] Put out the Key Concept sheet to sum up the ideas from the two models. Have learners refer back to these key concepts when they debrief the models further.

4. Point out strengths and weaknesses of the model. Say, **“This model shows some things well and doesn’t show other things well. It is good for tracking how carbon atoms move through the system. On the other hand, it shows far fewer flows and reservoirs, and it doesn’t show that some flows and reservoirs are much bigger than others.”** Have groups gather their paper clips and put them back in the bags. Collect all materials.

5. Define carbon cycle. Tell learners that the models they have been working with are models of the carbon cycle—how carbon cycles/flows throughout Earth systems.

6. Debrief learning from the models with Keeling Curve graph. Show the Keeling Curve graph. Point out that the black trend line is the one you would like learners to pay attention to.

a. **Give learners a minute to look at the graph and talk to a partner about what they think the graph shows.** (*Learners might wonder what parts per million refers to. Let them know it is the number of CO₂ molecules in the atmosphere for every one million molecules. So, one part per million would mean one in a million. They may also wonder why the red line squiggles. If it seems appropriate, share that the red squiggles represent seasonal variation. About half the year, CO₂ levels are on the lower end because trees have all of their leaves and are taking in lots of CO₂. The other half of the year, the trees are barren and don’t take much CO₂ out of the atmosphere. You can refer back to the photosynthesis flow card to clarify what you mean.*)

b. **Have learners share out their ideas about what the graph shows.** [Atmospheric CO₂ has been rising since 1958.] Ask, **“Based on the evidence you gathered during the carbon cycle paper clip games, why do you think you are seeing the trend you see on the Keeling Curve graph.”** Give learners a minute to discuss their ideas with a partner or the group. Encourage learners to consider and build on each other’s ideas by asking questions like, **“What do others think about that idea? Do you agree or disagree with that idea? Why? What makes you think that?”** If no one mentions it, share that all of the excess CO₂ going into the atmosphere from burning fossil fuels isn’t flowing back out of the atmosphere reservoir into other reservoirs as fast as it is entering.

7. Discuss implications for reducing carbon in the atmosphere. Ask, **“Based on what you learned from the paper clip game, what do you think people could do to decrease the amount of carbon in the atmosphere?”** Allow learners to discuss their ideas. Prompt them to provide evidence if needed by asking questions like, *“What makes you think that? What is your evidence?”* Ask if anyone agrees or disagrees with the ideas being offered and why.

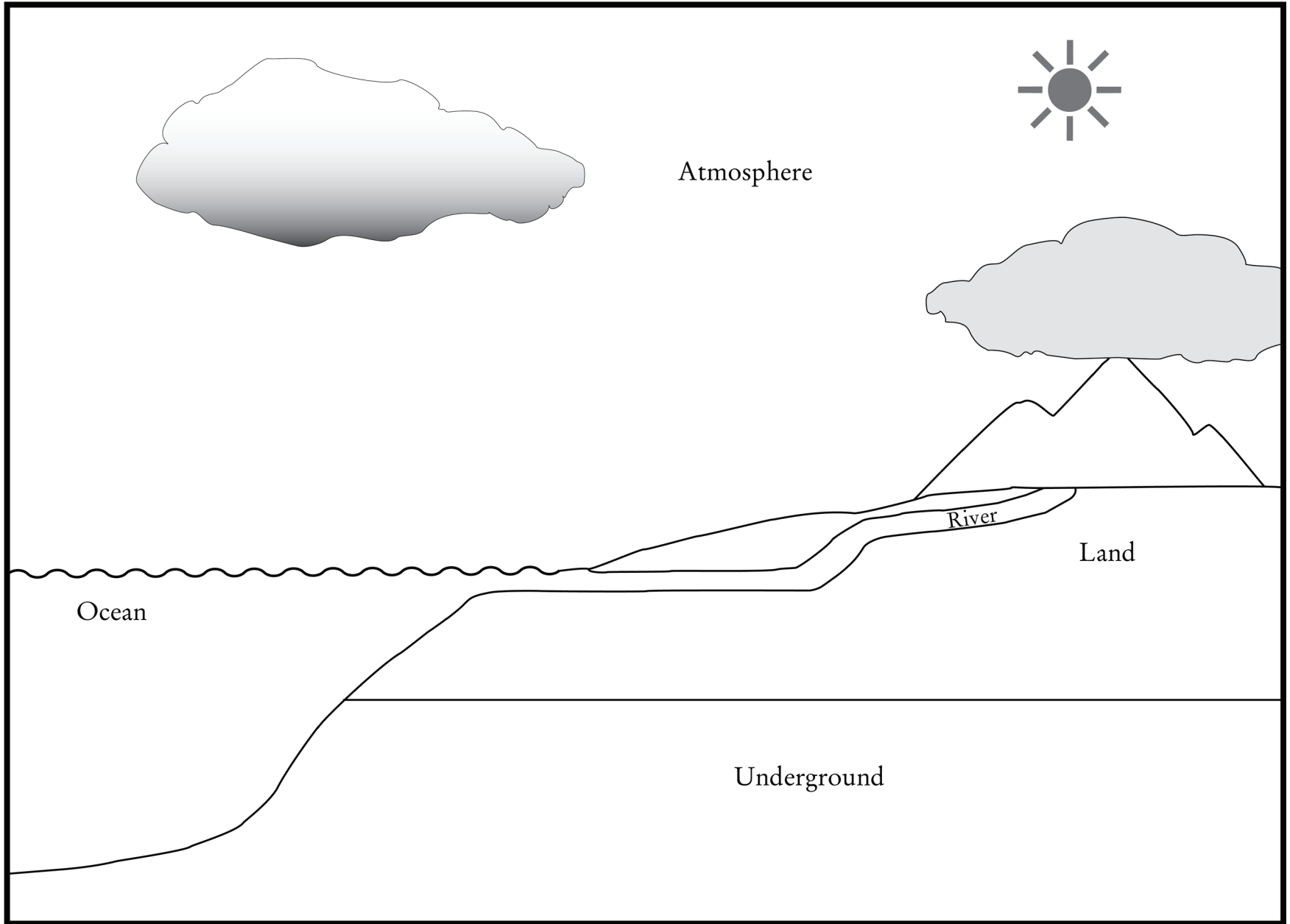
8. Explore the carbon cycle interactive. If learners are still interested, allow them to play around with the interactive carbon cycle diagram computer model. Check in from time to time and ask if they are finding anything interesting or surprising. Encourage learners to click on flows and reservoirs to find more information. Also encourage them to use the tabs at the top of the interactive to see different flows. Some learners might even want to do the math and calculate how much carbon is flowing into the atmosphere and how much is flowing out. If they use just the natural flows, the numbers will balance. If they add in human industry, more carbon will be entering the atmosphere than leaving. You may wish to share the “how much is a gigaton?” sheet with learners if they seem to be interested in calculating numbers.

9. Find out about the effects of increasing atmospheric carbon dioxide. At this point, many

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learners will be curious to find out more. Encourage learners to visit the greenhouse effect activity, the sea level rise activity, and the ocean acidification activity.

Carbon Cycle Diagram



Science Background

The Carbon Cycle

The carbon cycle on Earth is the system of reservoirs containing carbon and the flows that move carbon between these reservoirs. The carbon cycle includes living things (both on land and in the ocean) taking in carbon from the atmosphere through photosynthesis and then later returning carbon to the environment through respiration, decomposition and decay, fossil fuel formation, and combustion.

Understanding the carbon cycle is key to understanding the causes, effects, and solutions to climate change. By understanding how and where, as well as how long, carbon is stored in Earth's various reservoirs and how it flows between them, students can gain an appreciation of natural processes and man-made processes involved in maintaining and changing Earth's climate. The ocean plays an especially important role in the carbon cycle with regard to climate change, as the ocean absorbs a significant amount of excess CO₂ from the atmosphere.

Carbon Reservoirs

Carbon reservoirs are places where carbon is stored for a period of time until it flows to another location. These reservoirs contain not only carbon, but many other elements as well. The carbon in a particular reservoir may be part of one or more of the many types of molecules containing carbon that are found on Earth and could be present in gaseous, liquid, or solid states.

Carbon moves between different reservoirs, but the total amount of carbon on Earth remains the same. Carbon reservoirs, in size order from largest to smallest, are limestone and other rocks, sediments and sedimentary rocks, ocean water, fossil fuels (natural gas, crude oil, and coal), soil, the atmosphere, plants, and animals. The average time that carbon stays in these reservoirs varies from days to weeks to years to millions of years, depending on the nature of the reservoir.

Earth's Crust (limestone and other rocks, sediments and sedimentary rocks, fossil fuels, and soil). About 99 percent of all carbon on Earth is locked up in sediments and sedimentary rocks. It is also stored in fossil fuels such as coal, oil, and natural gas and in carbonate-based rock such as limestone, dolomite and chalk. Dead organic matter, litter, and humus in soil are another carbon reservoir within Earth's crust. All these carbon reservoirs are important, not just because together they form the largest repository of carbon on Earth, but also because human industry has dramatically increased the flow of carbon out of them.

The Ocean (deep ocean water and ocean surface water). The ocean covers over 70 percent of Earth's surface and has an average depth of almost 4,000 meters. Because it is so large, the ocean holds a great deal of carbon—approximately 38,000 gigatons. Carbon in ocean water is found in different forms, such as dissolved carbon dioxide (CO₂) and carbonic acid (H₂CO₃). Carbon in the ocean is important for phytoplankton, which take in carbon dioxide as part of photosynthesis, and for shelled animals, which use carbon in their calcium carbonate (CaCO₃) shells. Ocean surface water and deep ocean water can be considered as distinct carbon reservoirs, since the flows of carbon are quite different for surface and deep water. The ocean as a carbon reservoir plays an important role in the carbon cycle because there is a great deal of flow between the atmosphere and ocean, both through photosynthesis and diffusion, and because many geologic carbon reservoirs form through interactions with the ocean.

Earth's Atmosphere. The atmosphere is a layer of gases surrounding Earth, held close by Earth's gravity. The atmosphere begins right at Earth's surface where most of its mass is

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concentrated in the first 11 kilometers (km). About 100 km out, the atmosphere becomes so thin, that it is now the place we call outer space. Earth's atmosphere is composed primarily of nitrogen and oxygen, with less than 1 percent being composed of carbon dioxide (CO₂), methane (CH₄), and other gases. The carbon-based gases it contains make it a medium-sized reservoir of carbon—roughly 800 gigatons of carbon, with an average residence time of 3.6 years. This means that carbon remains in the atmosphere for approximately 3.6 years before flowing into another reservoir. Some carbon-based gases remain in Earth's atmosphere longer than others; carbon dioxide (CO₂) may remain in the atmosphere for as little as 30 years and as long as 95 years.

The atmosphere plays a critical role in keeping our planet habitable. It contains the gases that organisms use for respiration, photosynthesis, and other physiological processes, and it maintains a moderate global temperature. Carbon dioxide (CO₂), methane (CH₄), water vapor (H₂O), and some other gases in the atmosphere are known as heat-trapping gases. These gases transmit most of the light energy (from sunlight) heading through the atmosphere toward Earth's surface. When this light energy warms Earth's surface and heat energy is re-emitted from Earth's surface through the atmosphere, these gases reflect much of that heat energy back toward Earth. The increase of these heat-trapping gases in the atmosphere is causing an increase in average global temperatures.

Organisms (plants or other photosynthetic organisms and animals). Every cell in every living thing is partly composed of carbon; DNA, sugars, cellulose, proteins, and many, many others, all include carbon. Carbon-based molecules play a key role in how organisms get energy—through photosynthesis in the case of plants, algae and other plantlike organisms, through eating other organisms or decomposing material from other organisms in the case of animals, fungi and others. It should be noted that the plant carbon reservoir includes all photosynthetic organisms, and the animal carbon reservoir includes all non-photosynthetic organisms.

Carbon Flows

A carbon flow is a way in which carbon moves from one reservoir to another. The processes of respiration, photosynthesis, absorption of CO₂ into the ocean, decomposition, fossil fuel formation, and combustion account for most of the flows in the carbon cycle. While moving, carbon often becomes part of different kinds of molecules (e.g., CO₂, CH₄, CaCO₃). And its phase (solid, liquid, or gas) may also be different before and after a flow. For example, when coal combusts, carbon goes from being part of a solid in relatively large hydrocarbon molecules to being part of a gas in three-atom carbon dioxide molecules.

Some flows are much larger than others. The largest carbon flows move about 100 gigatons of carbon per year and include the processes of photosynthesis and plant respiration, flows between the ocean and atmosphere, and flows between the ocean surface and deep ocean. All these flows and a few others occur naturally. But three flows are not natural: (1) changing how land is used, (2) burning fossil fuels, and (3) making cement. Human industry has instigated these man-made carbon flows, and that has impacted the overall carbon cycle and its equilibrium.

Flows into the Atmosphere.

Ocean to Atmosphere. A great deal of carbon flows back and forth between the ocean's surface and the atmosphere. About 90 gigatons of carbon per year, in the form of carbon

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dioxide, moves from ocean water into the atmosphere. Roughly the same amount is absorbed each year from the atmosphere into the water at the surface of the ocean.

Plants and Animals to Atmosphere. Organic processes move significant amounts of carbon into the atmosphere through respiration, including ruminant digestion, and gases released when living things decompose.

Respiration. Respiration moves carbon as carbon dioxide from the reservoir of living things on land, or at the surface of the ocean, into the atmosphere. The term *respiration* is commonly used to refer to simply breathing, inhaling and exhaling gases, but that is only part of the process. Cellular respiration occurs in all cells, and it is how organisms obtain the energy to grow and function. *Respiration* is the process of taking in oxygen, using that in a chemical reaction to break down sugars from food in order to release energy, and disposing of carbon dioxide, which is a product of the reaction. Respiration can be represented in the equation: $C_6H_{12}O_6$ (sugar) + $6O_2 = 6CO_2 + 6H_2O + \text{energy (36ATP)}$. This is *aerobic respiration*, respiration in which oxygen is a reactant and carbon dioxide and water are its products. Many organisms employ *anaerobic respiration*, respiration where oxygen is not a reactant and other products result. One kind of anaerobic respiration occurs in the guts of animals during digestion and that process releases carbon in the form of methane gas.

Ruminant Digestion. Methane gas (CH_4) is a byproduct of digestion in some animals, and a significant amount is released into the atmosphere. In particular, cows release a large amount of methane. Cows emit massive amounts of methane through burps, with a lesser amount through flatulence. Statistics vary regarding how much methane the average cow expels, but some experts say 200 to 400 pounds per year. It is estimated that agriculture is responsible for 14 percent of the world's heat-trapping gases. Why do cows produce so much methane? Cows, goats, sheep, and several other animals belong to a class of animals called ruminants. Ruminants eat food (grasses) that they could not digest without the help of anaerobic bacteria that live in their multiple stomachs. The bacteria make the food usable for the animals, and the process produces methane, which is expelled into the atmosphere.

Gas from Decomposition. In the process of breaking down plants and animals, decomposers (bacteria, fungi and other organisms) release both carbon dioxide and methane (CH_4) into the atmosphere, depending on whether the process happens either aerobically or anaerobically. Organic material decomposing with oxygen is an *aerobic* process and CO_2 is released. Generally, aerobic organisms respire about two-thirds of the carbon they consume as CO_2 , while the other third is combined with other molecules and nutrients in their cells. *Anaerobic* decomposition takes place when dead organisms decompose underwater or underground where oxygen and microorganisms that use oxygen are not present. In this case, carbon from organic compounds is released mainly as methane gas. If the decomposition is taking place underwater, the gases dissolve in the water and are usually released slowly into the atmosphere. Together, both aerobic and anaerobic decomposition account for 30 gigatons of carbon entering the atmosphere each year, either in the form of CO_2 or CH_4 .

Flows from Earth's Crust to Atmosphere. Carbon flows in this category can be divided into those that occur naturally—a combined total of .08 gigatons—and those that happen because of human industry—a combined total of 9.4 gigatons.

Natural Flows: Earth's Crust to Atmosphere (natural leakage and breakdown of fossil fuels and volcanic eruptions). A very small amount of carbon moves naturally from Earth's crust to the atmosphere. Volcanic eruptions from rocks deep in Earth's crust and the natural leakage of tiny quantities of fossil fuels to the surface each release small amounts of carbon dioxide into the atmosphere.

Human Industry: Earth's Crust to Atmosphere (combustion of fossil fuels, land-use

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change, and making cement). Although fossil fuels release carbon into Earth's atmosphere through natural processes, this generally happens very slowly, with approximately 0.05 gigatons of carbon entering the atmosphere per year. Since the start of the Industrial Revolution, however, human industry has released carbon from Earth's crust into the atmosphere much more rapidly. Combustion of fossil fuels from human industry releases an additional 7.6 gigatons of carbon per year. When fossil fuels combust, hydrocarbon molecules in the fossil fuel react with oxygen molecules in the air. One product of this reaction is carbon dioxide, which moves into the atmosphere. Making cement from limestone also releases an additional 0.3 gigatons of carbon per year. In addition, humans have decreased the flow of carbon out of the atmosphere through land-use changes in which they created cities in places plants used to live and through deforestation. In total, human activity accounts for approximately 9.4 additional gigatons of carbon being added to the atmosphere each year, and the flows into the atmosphere are not balanced by natural flows out of the atmosphere. This increase in atmospheric carbon has dramatic impacts on Earth, such as climate change and ocean acidification.

Flows into and within the Ocean.

Atmosphere to Ocean. Carbon enters the ocean reservoir from the atmosphere by absorption, where it dissolves because of diffusion (moving from places of higher to places of lower concentration). The difference between the concentration of carbon dioxide in the ocean and the atmosphere causes CO₂ to move rapidly between the two in order to equalize concentrations. Once in the ocean, CO₂ dissolves and forms carbonic acid and bicarbonate and carbonate ions. This means that the concentration of CO₂ in the ocean has decreased, so more CO₂ diffuses into the ocean, and the ocean absorbs more CO₂.

This process is affected by water temperature—colder water absorbs more CO₂, warmer water absorbs less. Another influence is surface winds; they agitate ocean surface water and speed up the process of absorption.

Organisms to the Ocean. Respiration by ocean organisms adds carbon dioxide to ocean water, just as respiration by organisms on land adds CO₂ to the atmosphere. Similarly, waste from ocean organisms and decomposition of dead organisms also adds carbon to ocean water.

Surface to Deep. Nearly all ocean organisms are found in shallow waters (down to 100 meters or 330 feet) where there is enough light to support photosynthesis for microscopic organisms, such as phytoplankton. It is here in the surface water that carbon is transferred through the ocean food web. As ocean organisms release mucus, fecal matter and eventually die, there is a constant sinking (due to gravity) of carbon-based waste products and dead organisms down to the deep ocean. Ocean scientists call this falling material, *detritus* or "marine snow" because it glows white in their deep-sea submersible lights. As it sinks, much of the detritus is eaten by other animals, dissolved in the ocean water, or decomposed by bacteria, but about 10% reaches the deep ocean (100 gigatons per year). Decomposers in the cold, deep ocean continue to slowly break down the detritus, releasing carbon dioxide gas and leaving shells and skeletons and other matter that doesn't decompose to become ocean sediments.

Deep to Surface. Upwelling is a mechanism in which cold, deep ocean water is brought up to the ocean surface. Deep ocean water is cold and contains the organic compounds and nutrients from all the dead and decomposed ocean organisms that have sunk due to gravity. Up in the surface sunlit zone, the nutrients, such as phosphates and nitrates, act as a super-rich fertilizer for phytoplankton and other plantlike organisms, and the entire food web blooms in a dramatic fashion. These areas, where the deep ocean water comes to the surface constitute about one percent of the surface of the ocean, yet they account for 50 percent of the worldwide fisheries catch! There is upwelling off the west coasts of North America, South America, Africa,

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and Australia, and off the coasts of Spain and Portugal and around Antarctica. Most of the areas where upwelling occurs are on the west coasts of continents, because of the winds and currents working together, in combination with the rotation of Earth.

Flows into Organisms.

Atmosphere to Organisms (photosynthesis). Photosynthesis creates the largest single flow of carbon on Earth. It is important for creating the oxygen we breathe and is the primary source of food to sustain life on Earth. Photosynthesis is a chemical process by which plants, algae, and many types of bacteria use energy from the sun to convert CO₂ and water to organic compounds, especially sugars. Oxygen is released as a waste product. Photosynthesis happens both on land and in the ocean, and in fact, half of all photosynthesis on Earth happens in the sunlit upper layers of the ocean. On land, plants can absorb CO₂ directly, but in the ocean, plantlike organisms (phytoplankton) use CO₂ that has been dissolved in seawater.

Many learners struggle with the idea that gases are composed of matter and that these gases can be converted to something solid, such as cellulose, which forms roughly 33 percent of all plant matter. This is likely because most gases are invisible and don't seem to have any substance. It may also explain why some people assume that plants obtain material to grow through their roots from the soil, water, and minerals. Based on research about the development of conceptual understanding in science, it seems clear that simply learning about the equation for photosynthesis and reading about it does not ensure that learners will fully understand this important concept.

Organisms to Organisms (animals eating). Organisms that cannot produce their own food must consume other organisms or parts of other organisms. This includes all animals and fungi and many bacteria. When an animal eats another organism, carbon in that organism moves into the animal. Many organisms take in carbon from other organisms in ways that can't properly be called "eating," either through decomposition of dead organisms or droppings, or through parasitism.

Flows into Earth's Crust.

Organisms to Earth's Crust (plant and animal decomposition, sedimentation and burial, deep ocean to sediments and sedimentary rocks). Carbon flows in this category can be divided into three main groups: those involving decomposition of living organisms, those forming sediments and sedimentary rocks, and lastly, fossil fuel (coal, crude oil, or natural gas) formation.

Decomposition and Sedimentary Rock Formation. Decomposition is the process by which organic substances, such as animal droppings, dead organisms, or parts of organisms (such as fallen leaves) are broken down into simpler forms of matter. Larger organisms, such as earthworms, woodlice and maggots feed on dead matter and break it down into smaller pieces. This increases the surface area for the bacteria and fungi, which cause decay at a microscopic level. By breaking down complex carbon structures in dead plants and animals and rebuilding new ones or storing the carbon in their own bodies, decomposers play an important role in cycling nutrients. Not all of the products of decomposition, however, are used by these organisms. As an organism, or parts of an organism, decompose, significant quantities of carbon enter the soil. (Some carbon from decomposition on land also enters the atmosphere, and some carbon from decomposition in the ocean enters ocean water.) As soil or other sediments (containing carbon from organisms or partially decomposed pieces of organisms) are buried under successive layers of sediment deposits, the sediments may be compressed and heated, forming sedimentary rock. One example is limestone, which is formed when sediments

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composed largely of animal shells—calcium carbonate (CaCO_3)—are heated and compressed. Through further compression and heating, limestone can be converted into marble.

Carbon flows out of the ocean reservoir when it is converted into shells by ocean organisms, and as shelled and non-shelled ocean organisms die and decompose, they (including the carbon in their bodies), sink slowly to the bottom of the ocean. When this carbon reaches the bottom of the ocean, it helps form sediments and eventually becomes sedimentary rock.

Fossil Fuel Formation (coal, crude oil, and natural gas). When dead organisms are buried without decomposing, fossil fuels may form. The formation of fossil fuels requires very specific conditions that are different for each fuel type.

Coal is formed from plant matter. Normally, when a plant dies, it begins to decompose. The plant matter is broken down by decomposers, such as bacteria, fungi, and microbes that require oxygen to survive. Through decomposition, carbon moves from the plant matter into the decomposer's body, is released by the decomposer as CO_2 , or enters into the soil. However, if the plant matter is buried under layers and layers of sediment that do not have oxygen and thus do not have decomposers, the carbon compounds in the plant are not broken down. Over millions of years, increased temperature and pressure may turn the plant matter into coal. A swampy, heavily vegetated environment is ideal for forming coal. Much of the coal we use today was formed during the Carboniferous period, about 360–300 million years ago when environments such as this were widespread. Trees and other plant matter fell into pools where they were quickly covered by mud. Over time, the plant matter was heated and compressed as more and more mud was deposited on top of it. As the material broke down, the composition was altered and deposits became more and more carbon-rich as other elements dispersed; ultimately forming a coal deposit. It is estimated that it takes 10 feet of plant material to make 1 foot of coal deposits.

Crude oil formation begins with the accumulation and decay of dead organisms (animal and photosynthetic organisms) on the floor of the ocean or lakes. Similar to the process of forming coal, the dead organic material is covered with layer after layer of silt and mud, which excludes decomposers that require oxygen. Over millions of years, increased temperature and pressure may turn the matter into oil. The heat and weight of these layers squeeze out the water and cause the stored energy (carbon compounds) in the organic material to break down into a liquid phase of carbon as crude oil. The silt and mud eventually compress into rock leaving the organic materials trapped between two layers of rock, which act like a cap or seal that prevents the oil from escaping to the surface. The reason that a lot of oil drilling occurs at sea is simply because the majority of Earth's crust, in which the oil is located, is covered by the ocean. Oil deposits that are pumped from dry land today occur in places that were once covered with water when the oil formed.

Natural gas is primarily (99%) methane. In watery environments on land and at the bottom of the ocean, some dead organisms get buried rather than decomposing. Over millions of years and under the high pressures and temperatures underground, some of the buried material becomes natural gas, and the rest becomes coal or crude oil. Natural gas forms in two ways, mainly dependent on whether or not microorganisms are present and the depth at which the dead organisms are buried. At shallow depths, bacterial decay and growth of fungi and other microorganisms break down the deposited material. A primary product of this metabolic activity in conditions without oxygen is the release of methane gas.

At greater depths, microbial activity is diminished. It is the increased temperatures and pressures that drive off water and other volatile materials and also break down the hydrocarbon molecules into smaller molecules. In general more crude oil and coal than natural gas is formed at low temperatures (shallower deposits) and more natural gas than crude oil and coal is formed

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at higher temperatures (deeper deposits). Natural gas is less dense than crude oil and coal so it rises to the top of crude oil and coal deposits.

Atmosphere to Earth's Crust (precipitation and weathering of rocks). As rainwater falls, it dissolves small amounts of atmospheric carbon dioxide to form carbonic acid (H_2CO_3). This weak acid can react with the chemicals in rocks and break them down. In some rocks, this weathering can ultimately cause the release of carbonate (CO_3^{2-}) into the waterways. Weathering initiated by this weak carbonic acid accounts for 0.1 gigaton/year of carbon from the atmosphere being released into waterways.

Human Impact on the Carbon Cycle

Burning of Fossil Fuels. Some human-made processes transfer carbon from one reservoir to another much faster than it would happen naturally, such as the burning of fossil fuels. Naturally, carbon from fossil fuels that took millions of years to form would remain sequestered for around 100,000 years and be released by natural leakage and breakdown. However, combustion of fossil fuels releases carbon into Earth's atmosphere immediately, which rapidly increases the amount of carbon in Earth's atmosphere because it builds up there faster than it can flow into other reservoirs. The increase of carbon in the atmosphere is causing an increase in global average temperatures. Increasing temperatures cause the melting of glaciers and sea ice, rising sea level, changes in regional climates and patterns of ocean currents, and can have large impacts on people and other organisms.

Deforestation. Each year, an area of rainforest almost the size of South Carolina is destroyed. Rainforests absorb so much CO_2 from the atmosphere that the ongoing destruction of rainforests by slashing and burning is now one the major causes of additional CO_2 in the atmosphere. Recent studies show that deforestation accounts for around 11.3 percent of human-caused global emissions of CO_2 . Transportation accounts for 14.3 percent, industry accounts for 14.7 percent, agriculture 14 percent, and electricity and heat accounts for 25 percent; see <http://www.wri.org/chart/world-greenhouse-gas-emissions-2005>. This increased amount of CO_2 in the atmosphere includes the CO_2 that is no longer taken in through photosynthesis by the destroyed forests as well as the CO_2 produced from burning the forests. Forests are destroyed in order to provide room for growing crops or grazing livestock, make room for human development, or produce paper and other wood products. Financial realities make it highly unlikely that humans will be able to stop rainforest destruction altogether. However, planting new trees to replace felled ones and eliminating the practice of clear-cutting, which destroys entire forest ecosystems are realistic and responsible ways of preventing the damage currently caused by deforestation. Deforestation has particularly large impacts on the tropics.

Ocean Acidification. As the ocean takes in more and more CO_2 from the atmosphere, it is becoming increasingly acidic. This is because CO_2 dissolving in water produces H_2CO_3 (carbonic acid), a weak acid. The problem is that as the amount of CO_2 in the atmosphere rises from human industry, more is absorbed into the ocean and the acidity of the water rises more than would naturally occur. The ocean has already taken in so much CO_2 over the past 200 or so years that it has become about 30 percent more acidic (a -0.11 drop in average surface ocean pH). When the ocean becomes more acidic, it is called *ocean acidification*. As of 2006, or the past 260 years, atmospheric CO_2 has increased by 36 percent. (<http://www.epa.gov/climatechange/science/recentac.html>) The ocean has absorbed 25 percent of that CO_2 . One of the biggest problems associated with ocean acidification is that as the ocean gets more acidic, it makes it more difficult for some animals to build their CaCO_3 (calcium carbonate) shells.

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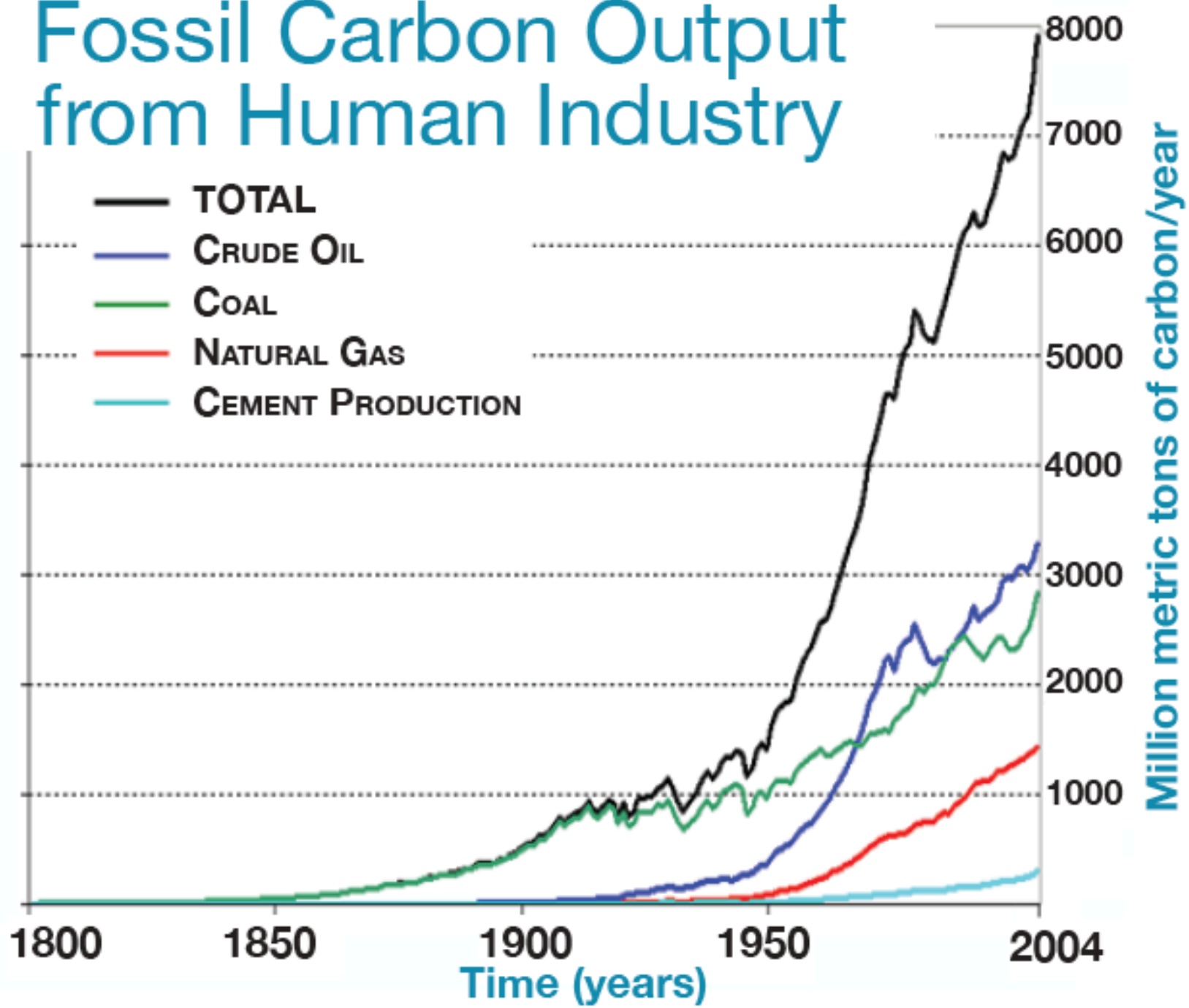
The background section is taken from Ocean Sciences Sequence: The Ocean–Atmosphere Connection and Climate Change. Used by permission from the Regents of the University of California. For more information and additional resources from this instructional material, see: <http://mare.lawrencehallofscience.org/curriculum/ocean-science-sequence/oss68-overview>.

Carbon: why is everyone talking
about it?

Focus Questions

1. Which reservoirs increase?
Which decrease?
2. Which reservoir gained the most atoms from different reservoirs?
(at end, has most clips in different colors)
3. What happens to the total number of carbon atoms on Earth?

Fossil Carbon Output from Human Industry



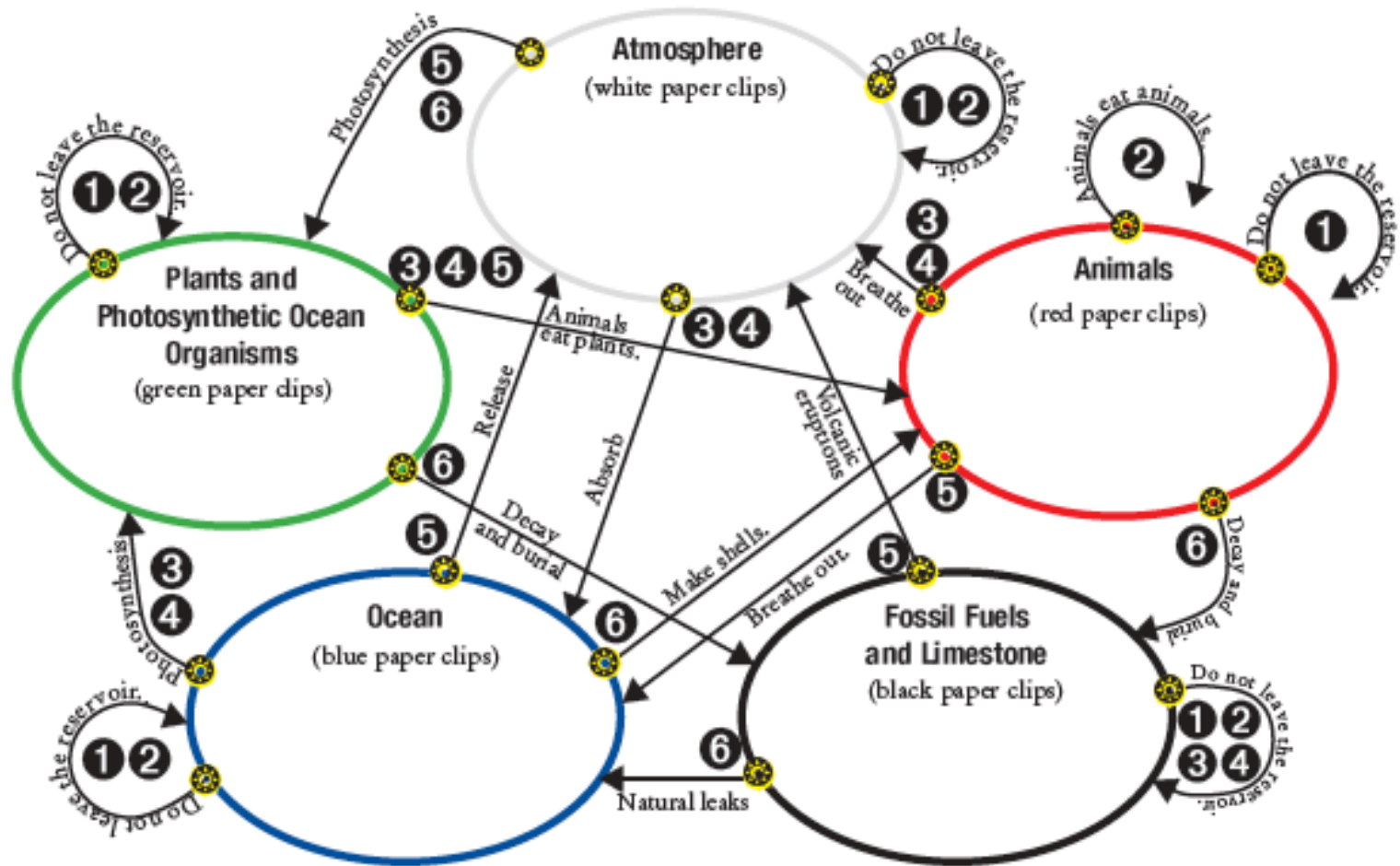


*Key
Concept*

2.7

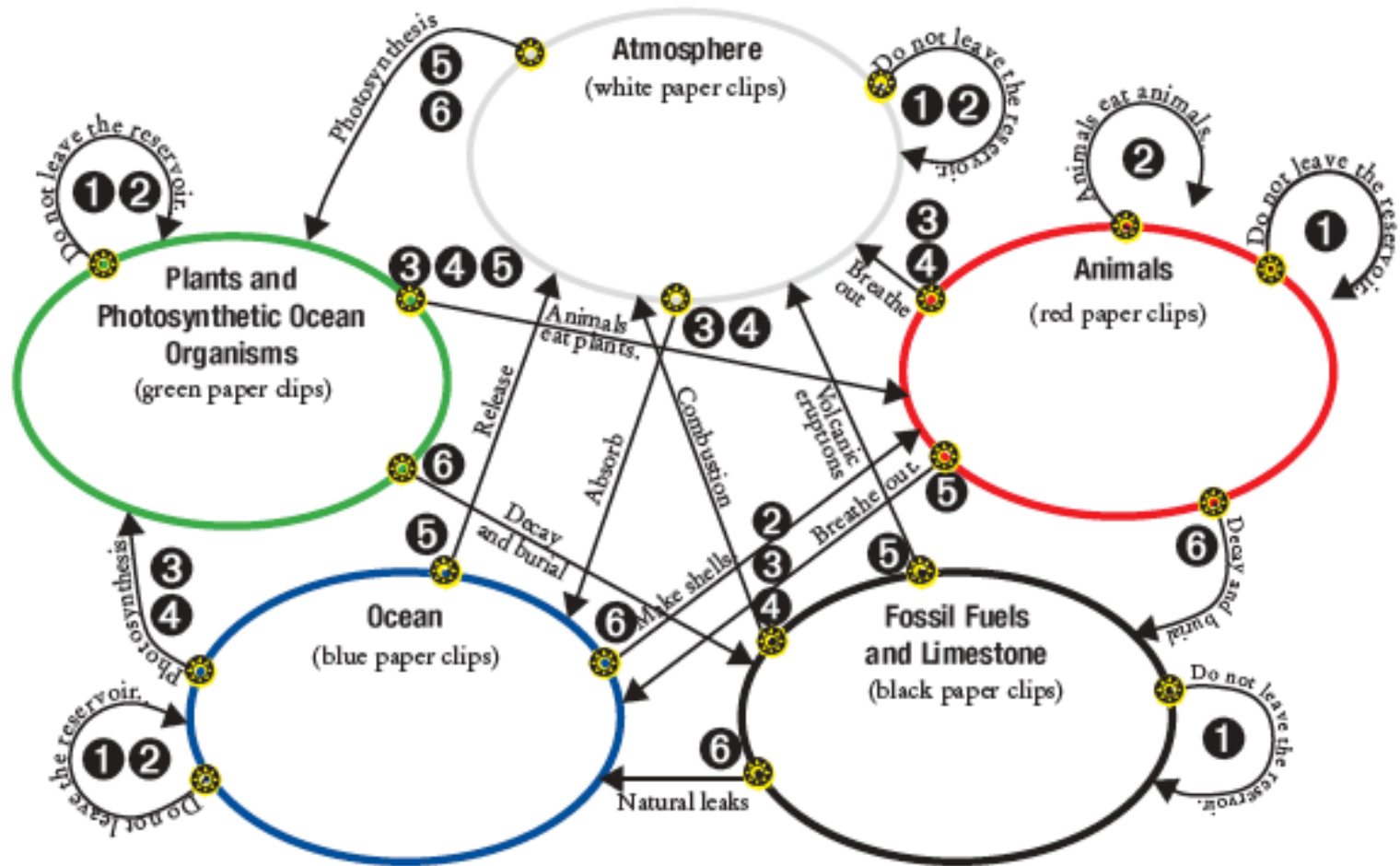
- **Carbon moves between reservoirs, but the total amount of carbon on Earth doesn't change.**
- **Human industry moves carbon out of fossil fuel and limestone reservoirs and into the atmosphere.**

Paper Clip Carbon Cycle Model #1



Student Sheet — Ocean Sciences Sequence 2.7

Paper Clip Carbon Cycle Model #2



Student Sheet — Ocean Sciences Sequence 2.7

How Much Is a Gigaton?

2.8

Gigaton = 1 billion tons (1,000,000,000)

That's about **170 million** African elephants!!

Keeling Curve: CO₂ Levels in the Atmosphere

