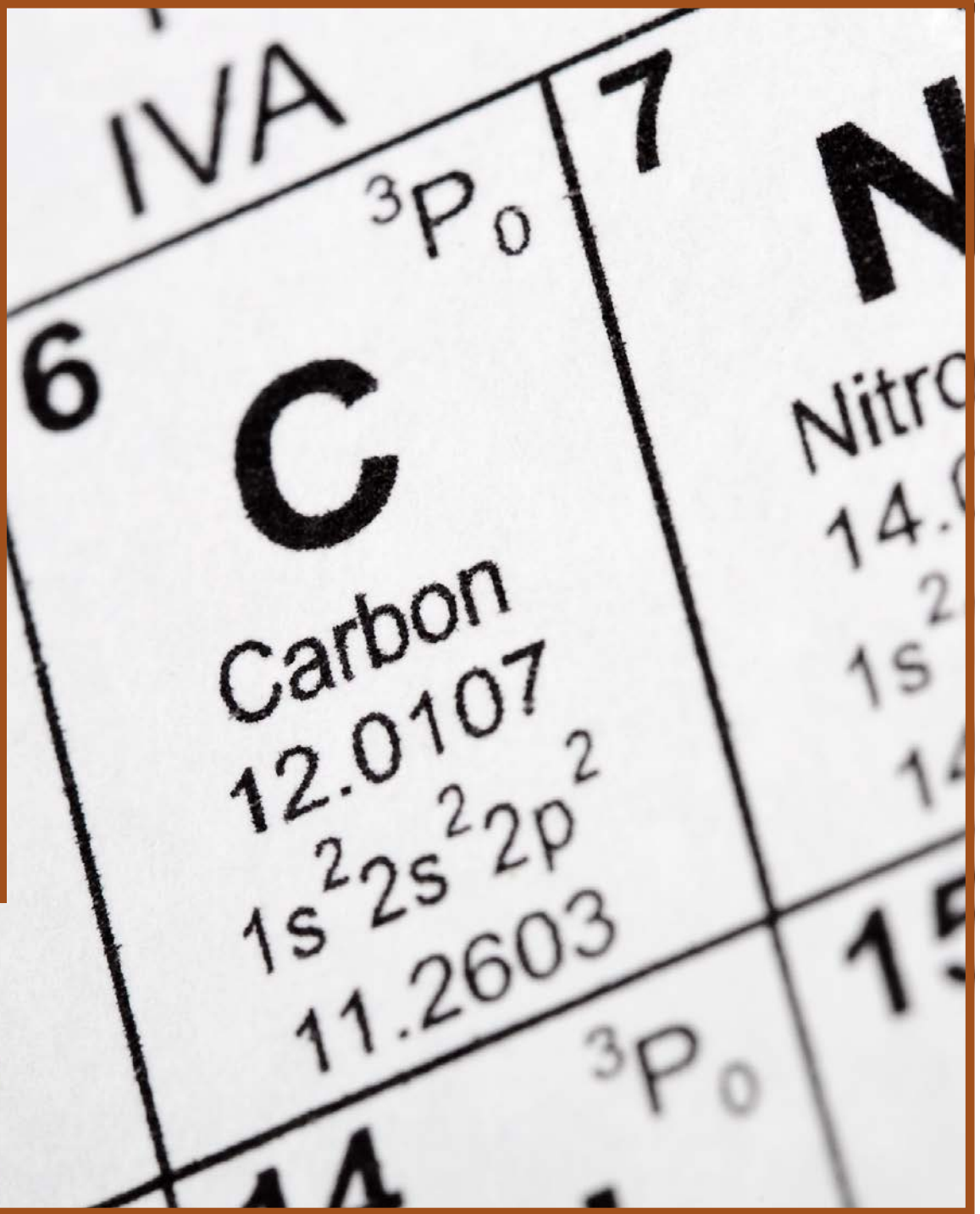


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The Life and Times of Carbon

California Education and the Environment Initiative

Approved by the California State Board of Education, 2010

The Education and the Environment Initiative Curriculum is a cooperative endeavor of the following entities:

California Environmental Protection Agency
California Natural Resources Agency
California State Board of Education
California Department of Education
Department of Resources Recycling and Recovery (CalRecycle)

Key Partners:

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Office of Education and the Environment

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Key Unit Vocabulary

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Abiotic: Related to the nonliving components or factors within or related to natural systems, such as soil, water, and temperature.

Biofuel: An energy source derived from biomass, such as plants, or from metabolic byproducts, such as animal manure.

Biogeochemistry: The study of biological, geological, physical, and chemical processes, and the cycling of matter and energy among these systems.

Biological pump: The mechanism that transports atmospheric carbon dioxide, other gases, and nutrients within organic matter as solids to the bottom of the ocean, that result from biological processes, such as photosynthesis, cell death, and sedimentation.

Biomass: The total mass of living matter in a given area; or, plant material (wood, grains, agricultural waste, vegetation) sometimes used as an energy source.

Biomass feedstock: A fuel source (including plant and animal wastes) that can be used to make biofuel.

Biotic: Related to the living components or factors within or related to natural systems, such as plants, animals, and microorganisms.

Carbohydrates: A large group of organic compounds, including sugars, starches, and cellulose, that contain only carbon, hydrogen, and oxygen.

Carbon: An abundant, nonmetallic element that is found in all living organisms and occurs in many nonliving materials.

Carbon cycle: The process by which carbon is exchanged between organisms and the environment (atmosphere, ocean, rocks, soil, and sediments).

Carbon flow: The movement of carbon in gaseous, dissolved, or solid form from one carbon reservoir to another.

Carbon flux: A change in the flow rate of carbon when it transfers from one reservoir to another.

Carbon footprint: The total amount of carbon gases produced directly and indirectly through human activities that use carbon-based fuels.

Carbon neutral: The state of being balanced between the production and use of carbon that results in no additional release of carbon dioxide into the atmosphere.

Carbon sink: A carbon reservoir that takes up more carbon than it is releasing or emitting.

Cellulose: A carbohydrate composed of complex sugars that comprises much of a plant's cell, especially the cell wall.

Climate change: A long-term significant change in the weather patterns of Earth.

Combustion: A process of burning that uses oxygen, generates heat energy, and releases carbon dioxide, as well as other gases.

Diffusion: The movement of a substance from an area of high concentration of that substance to an area of lower concentration.

Efficiency: The ratio of gain or waste to the amount of something used, expressed as a percentage.

Emissions: The release of matter or energy into the environment, including gases, particulates, noise, vibrations, light, heat, radiation, and odors.

Energy consumption: The total amount of energy involved in a process.

Ethanol: A type of alcohol that can be used as fuel.

Key Unit Vocabulary

Lesson 1 | page 2 of 2

Gigaton: One billion metric tons.

Mandate: An act that is required by law.

Permafrost: Permanently frozen soil at or below 0° C or 32° F.

Reservoir: A place where something is stored, like an artificial lake that holds water; or, a part of the Earth-atmosphere system that contains supplies of elements, such as carbon and nitrogen.

Sedimentation: The accumulation of layers of materials including detritus, sand, and soil, in locations, such as the ocean floor or a lake bottom.

Solubility pump: The process of carbon dioxide transfer from air to ocean, where it is distributed from the ocean's surface to its interior by mixing and ocean currents.

Switchgrass: A perennial grass native to North America, used as rangeland forage and hay.

Trade-off: The act of balancing several factors in a decision-making process; or, giving up one thing in order to get something else of value.

Weathering: The chemical or mechanical breakdown of rocks exposed to factors, such as wind and rain.

Name: _____

Where Can We Find Carbon?

Carbon compounds are everywhere around us. They are in our foods, plastics, soils, in water, in the air, and in our bodies. Carbon compounds can come in three physical forms: gas, liquid, and solid. Plants

take up carbon dioxide from the air, and use photosynthesis to turn carbon dioxide into carbohydrates. Carbohydrates are carbon compounds that store energy in the forms we call “starches” and “sugars.” About

three-fourths of the dry weight of plants is carbohydrates. In other words, when you look at plant matter (the stem, leaves, roots, and grains) you are looking largely at carbohydrates. Animals (including humans) get their carbohydrates by eating plants, but they do not store much of what they consume. In fact, less than 1% of the body weight of animals is made up of carbohydrates.

The main forms of carbon are: nonliving (abiotic) in rocks, soils, and sediments, and in water, such as bicarbonate, carbonate; living (biotic), such as plant and animal matter and dead organic matter; and carbon-based gases, such as carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO).

Chemists use a special system to describe compounds. They use a chemical formula of symbols that indicate the elements that make up chemical compounds. A chemical formula is also called a “molecular formula.” The chemical formula of carbon dioxide is CO_2 indicating one carbon atom bonded to two oxygen atoms. The symbol for carbon is C; for hydrogen is H; for oxygen is O; for silica is Si.



Coal heap

Collecting Carbon

Lesson 1 | page 2 of 4

Name: _____

Part 1

Instructions: As you rotate through the **Carbon Study Stations** and complete Column B of **Collecting Carbon** by listing the item's chemical formula.

	A	B	C
	Item	Chemical Formula	How Natural Systems or People Use Carbon in This General Form
1	Aspirin		
2	Breath of air		
3	Carbonated beverage		
4	CD		
5	Charcoal		
6	Corn		
7	Cotton		
8	Gasoline		
9	Glass Water		

Collecting Carbon

Lesson 1 | page 3 of 4

Name: _____

	A	B	C
	Item	Chemical Formula	How Natural Systems or People Use Carbon in This General Form
10	Hot dog (protein)		
11	Limestone (cement)		
12	Pencil lead (graphite)		
13	Plant material		
14	Plastic		
15	Seashells		
16	Stainless steel		
17	Vegetable oil (fat or lipid)		
18	Wood		

Collecting Carbon

Lesson 1 | page 4 of 4

Name: _____

Part 2

Instructions: After you have visited all the **Carbon Study Stations**, brainstorm how carbon is used in different forms in nature and by people. Make notes in Column C on the **Collecting Carbon** chart. (3 points each)

Part 3

Instructions: Independently, review your responses in Column C above and develop a summary statement that explains the importance of carbon to living organisms. (6 points)

Moving Through the Global Carbon Cycle

Lesson 2 | page 1 of 2

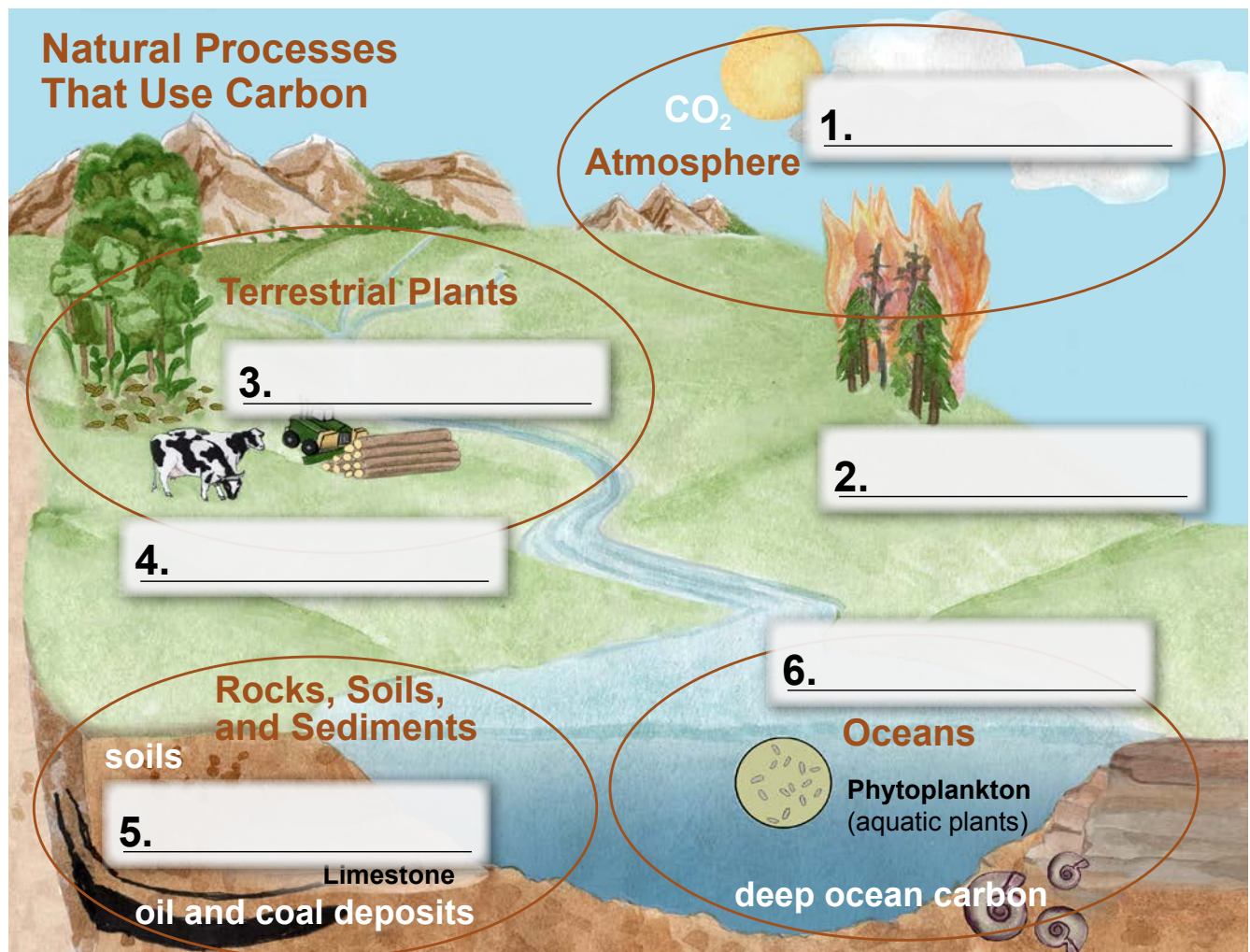
Name: _____

Instructions: Read and complete the tasks below.

1. List the four main carbon reservoirs, from greatest to smallest according to how much carbon each currently holds. (1 point each)

2. As a group, brainstorm how carbon moves from one reservoir to another. Use the following questions to guide your discussion:
 - What function does carbon serve in each reservoir?
 - What are the different natural processes involved in carbon movement?
 - How do people or natural systems benefit from these functions?

On each of the lines in the illustration identify a natural process that moves carbon to or from the reservoir. (1 point each)



Lesson 2 | page 2 of 2

- On the drawing shown add arrows between the processes and reservoirs to show the movement of carbon and carbon energy from one reservoir to another. (4 points)
- Briefly describe how people and other living organisms depend on the global carbon cycle for life. Explain how carbon cycles through each carbon reservoir and describe how carbon plays an important part in our communities, our lifestyles, and our economy. (10 points)

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Carbon Flow Observation Log

Lesson 3 | page 1 of 2

Name: _____

Instructions: Complete the following task in the chart below.

Carbon flow is the movement of carbon in gaseous, dissolved, or solid form from one carbon reservoir to another. As you play the **Carbon Flow Game**, describe the processes at work in each scenario and record how you believe carbon flows from reservoir to reservoir in the global carbon cycle.

Carbon Flow Observation Log		
Carbon Flow Card	Reservoir: Carbon Started Here	Reservoir: Carbon Moved Here
Feel the Burn		
Seeing the Forest Through the Trees		
Our Changing Landscape		
Fossil Fuels “Old-Growth” Carbon		

Carbon Flow Observation Log

Lesson 3 | page 2 of 2

Name: _____

Carbon Flow Observation Log

Carbon Flow Card	Reservoir: Carbon Started Here	Reservoir: Carbon Moved Here
Pumping Carbon		
How Permanent Is Permafrost?		
A Wetland "Wasteland?"		
Cement, Our Modern Building Block		
Made of Wood Is Good		

Name: _____

What Is Natural About Carbon Flow?

We know that photosynthesis results in the production of plant biomass and oxygen (O_2). Biomass is the green and brown stuff of plants—leaves, stems, trunk growth, and roots. Decomposition, on the other hand, is the breakdown of biomass—including animal matter. Decomposing plant and animal matter releases CO_2 to soils, the atmosphere, and the ocean. Most photosynthesis happens in the spring and summer months (the growing

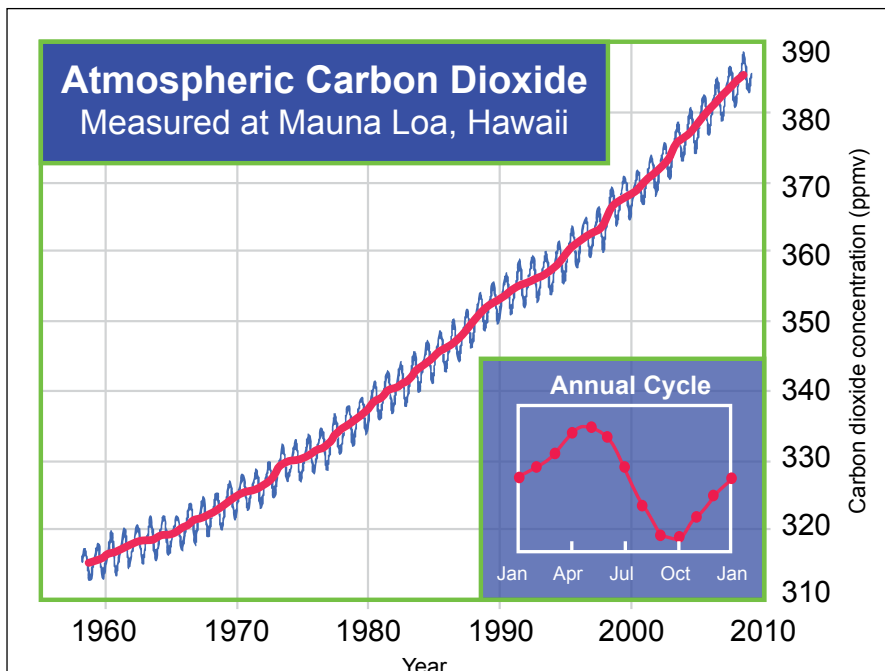
season), while most plant decomposition happens in fall and winter, when trees have lost their leaves.

Scientists have measured the annual differences in CO_2 uptake by photosynthesis and CO_2 emission by decomposition and respiration, and have discovered that it appears as if the Northern Hemisphere's photosynthesizers are “breathing”—an inhale of CO_2 in spring and summer, and an exhale of CO_2 in the fall.



Scientists have measured the annual carbon flow since 1958. The graph below shows that atmospheric carbon dioxide levels are highest in May just before plants rapidly increase their rates of photosynthesis, and atmospheric carbon dioxide levels are lowest near the end of the active growing season in October, before rapid decomposition releases CO_2 back into the atmosphere. This “breathe in” and “exhale out” is measured in this zigzag pattern each year.

Plants provide just one example of global carbon flow. Carbon dioxide is released to the atmosphere by a variety of natural sources, and together these sources account for over 95% of Earth's total CO_2 emissions.



Graph 1. Changes in atmospheric carbon dioxide from 1958 to present. Source: R. F. Keeling, S. C. Piper, A. F. Bollenbacher, and S. J. Walker, Carbon Dioxide Research Group, Scripps Institution of Oceanography, La Jolla, California, February 2009

Name: _____

Analyzing the Carbon Flow Game

Instructions: Using the **Carbon Flow Observation Log** (Student Workbook, page 10), compare your “Before Game” carbon data to the “After Game” carbon data, and complete the tasks below.

1. Complete the **Carbon Flow Summary Chart** below. To calculate the percentage change for each reservoir, divide the amount of “change of carbon” by the “before game carbon” amount. (For example, the “Rocks, Soils, and Sediments Reservoir” started with 14 total carbon pieces and ended with 8 total carbon pieces, for a change of -6 carbon stored.) (6 points)

$$-6 \div 14 = -42.9\% \text{ change}$$

Carbon Flow Summary Chart

Reservoir	Before Game Carbon	After Game Carbon	Change in carbon	Percentage Change in Total Carbon Storage
Rocks, Soils, and Sediments	14	8		
Ocean	6	8		
Atmosphere	2	7		
Terrestrial Plants	2	1		

2. Based on your calculations, what is the order of the carbon reservoirs from most changed to least changed? (1 point)

3. Which reservoir(s) took up more carbon than it released? (1 point)

4. As a percentage of change, which reservoir experienced the most loss of carbon? (1 point)

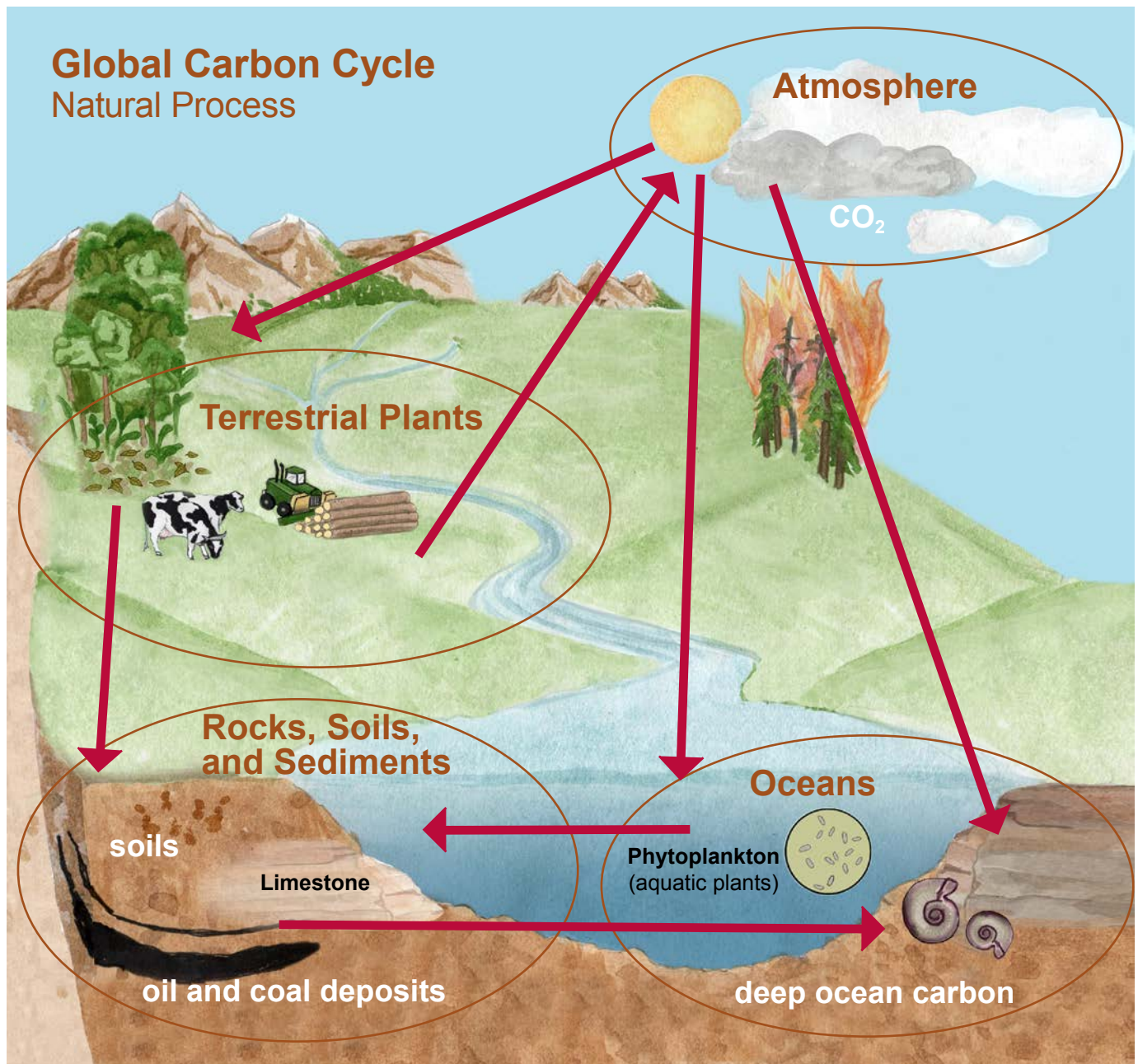
5. A “carbon sink” is a reservoir that is taking up more carbon than it is releasing. Based on the scenarios played in this game, which reservoirs might we consider being carbon sinks? (1 point)

Name: _____

Instructions: Use the diagram below to complete the tasks on the next two pages.

Cycling for Carbon

Earth's natural systems are very good at conserving energy and matter. The conservation of energy and matter is done through different natural cycles. Some scientists describe the movement of matter through cycles as a giant recycling station, where the “trash” products from one system are the “treasure” for another.



6. Write a brief explanation of what is meant by the phrase, "In the carbon cycle, the waste products of one system are the stuff of life for another."

- At least one example in your answer should describe one of following natural processes: the solubility pump, decomposition, forest fires, photosynthesis, respiration, sedimentation, subduction, or weathering. (1 point)
- Explain how the global carbon cycle results in a movement of carbon matter and energy. (1 point)
- Identify one carbon “sink” and describe why or how it acts as a carbon sink. (1 point)
- Use the following vocabulary words in your response. (1 point each)

carbon	energy	reservoir
carbon flow	global carbon cycle	sink

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Accounting for Changing Levels of Atmospheric Carbon Dioxide

Lesson 4 | page 1 of 4

Name: _____

Instructions: Read the following information, review the table below, and examine the diagram on the next page as you prepare to complete this assignment.

You have studied the different forms carbon takes (gases, rocks, plants, carbohydrates, proteins, fossil fuels, plastics, and others), the four major reservoirs that hold carbon, and the many different biogeochemical processes that move carbon throughout the global carbon cycle. Carbon is essential to living organisms, including people. The cycling of carbon by many different natural processes makes it available in different forms for us to use.

In the last lesson, you learned that a change in the amount of carbon that is moved from one

reservoir to another is called carbon flow. In this lesson, we will look more closely at the “accounting” of carbon flow: the amount of carbon cycled, and the timescales involved. Finally, we will consider recent changes in carbon flow, and how this affects the natural balance of the global carbon cycle.

The table below summarizes the distribution of carbon in the four major reservoirs on Earth: rocks, soils, and sediments; the atmosphere; the ocean; and terrestrial plants. (*Note: A gigaton is one billion metric tons.*)

Worldwide Annual Carbon Flow Between the Atmosphere and Other Reservoirs (gigatons)		
Reservoir	Amount of Carbon Released into the Atmosphere (Emissions)	Amount of Carbon Stored from the Atmosphere (Uptake)
Rocks, Soils, and Sediments	Carbon emission by soil respiration (decomposition by soil microbes): 60 CO ₂ from land use changes and burning fossil fuels: 8 (<i>Note: This is not considered a “natural” process, but is the result of human activities.</i>)	Measurements vary too much from location to location to accurately report data.
Ocean	Released back to atmosphere from respiration and decomposition: 90	Annual CO ₂ uptake by biological and solubility pump processes: 92
Terrestrial Plants	Carbon emission by decomposition/respiration: 50	CO ₂ uptake by photosynthesis: 111

Amount of carbon in each reservoir (gigatons):

Rocks, Soils, and Sediments: 66,000,000 to 100,000,000

Fossil Fuels: 4,000

Ocean: 38,000 to 40,000

Terrestrial Plants: 540 to 610

Atmosphere: 766

(The CO₂ concentration in the atmosphere is currently increasing by about 3.2 parts per million every year.)

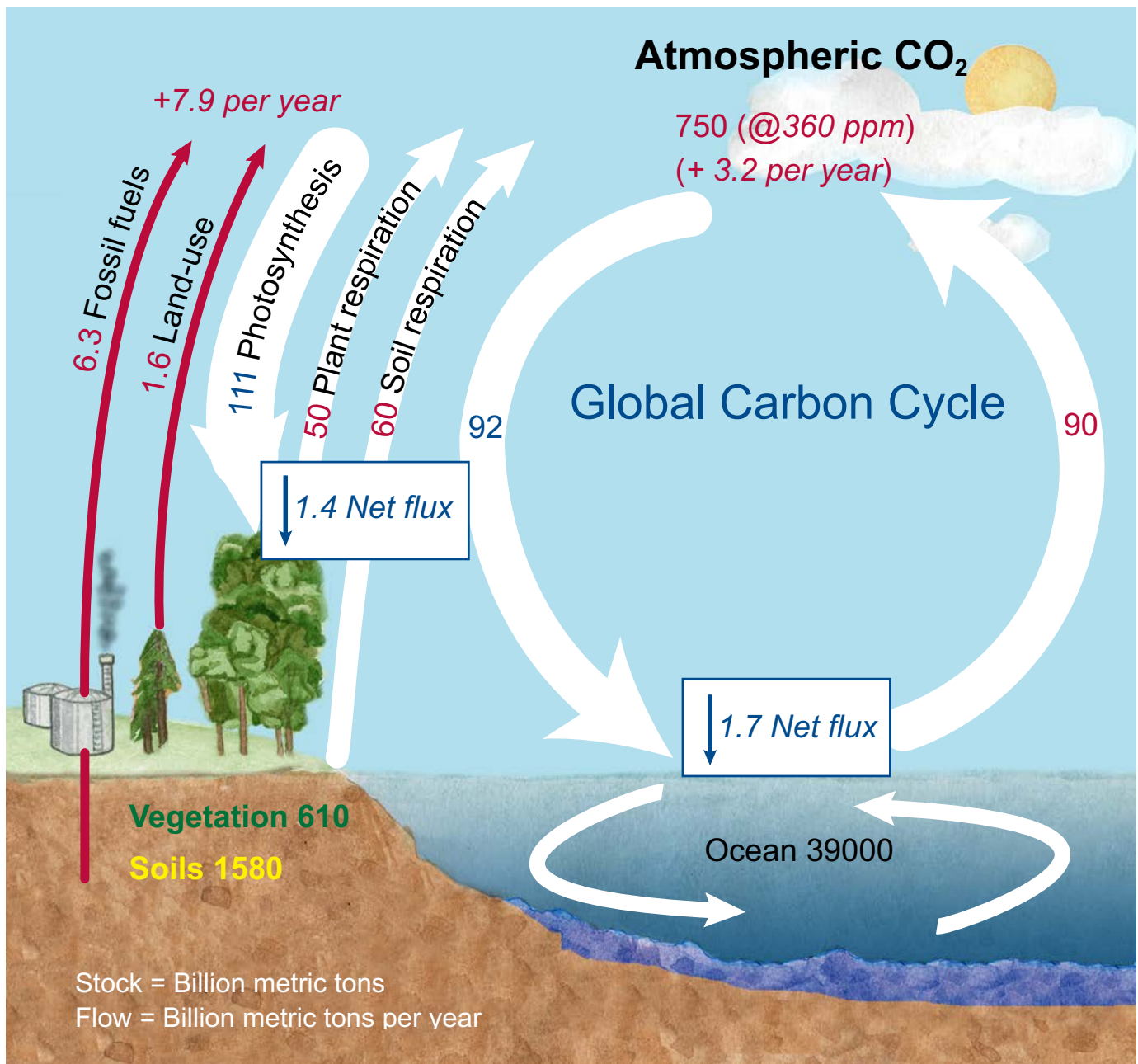
Accounting for Changing Levels of Atmospheric Carbon Dioxide

Lesson 4 | page 2 of 4

Name: _____

Global Carbon Cycle: This diagram shows carbon flow and includes both natural processes and human activities.

Carbon Flow Data



Source: http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/carbon_cycle/carbon_cycle.html

Name: _____

Instructions: Use the data provided on the **Worldwide Carbon Flow Chart** (page 1) and the **Carbon Flow Data** diagram (page 2) to answer the following questions.

1. Figure out the total natural carbon flow in gigatons from the reservoirs in the table provided. Compare the total carbon uptake from the atmosphere into other reservoirs by natural processes to total emissions into the atmosphere from other reservoirs by natural processes. To do the math, add up carbon stored and subtract carbon released as presented in **Worldwide Annual Carbon Flow Between the Atmosphere and Other Reservoirs**. (*Note: The stored carbon, or natural uptake, should be represented as a negative number, since it is carbon that leaves the atmosphere. The emissions, or carbon that enters the atmosphere, is represented as a positive number.*) (3 points)

Natural uptake	(-) _____
Natural emissions	_____
Net natural carbon uptake	= _____

2. Data Analysis: Even though rocks, soils, and sediments comprise the largest carbon reservoir, the amount of carbon flow to and from this reservoir is very small. Explain why this is. (2 points)

3. How do overall natural carbon emissions compare to overall natural carbon uptake? Would you expect this degree of “balance” in a natural cycle? In other words, does this “make sense” when you think about how a natural cycle should function? (5 points)

4. Consider the influence of human activities on the global carbon cycle: Figure the total carbon emissions from the combustion of fossil fuels (and biomass burning) and land use changes. Use **Global Carbon Cycle** on page 2 for fossil fuel emissions and emissions from land use to figure total emissions from human activities. (3 points)

Fossil fuel emissions	(+) _____
Emissions from land use	(+) _____
Emissions from human activities	= _____

5. Data Analysis: Where are most of these carbon emissions going? What carbon reservoir is taking up this carbon? (2 points)

Name: _____

6. Figure out the “Total Carbon Flow” to or from the atmosphere including flow from human activities. (Note: A positive number indicates carbon entering the atmosphere and a negative number indicates carbon leaving the atmosphere.) (3 points)

Carbon flow from natural systems _____
Carbon flow from human activities (+) _____
= _____

7. Data Analysis: What is the end result (in gigatons) of the “Total Carbon Flow”? (2 points)

8. What is the significance of “extra” atmospheric carbon dioxide in Earth’s atmosphere? (2 points)

9. What is really happening? Scientists are measuring an annual 3.2 billion metric tons of carbon dioxide entering our atmosphere from human activities on an annual basis. Scientists say that we are lucky: the ocean is currently taking up more carbon dioxide than it did under preindustrial conditions. Based on what you know about emissions of carbon dioxide due to human activities, explain why levels of atmospheric CO₂ have steadily increased the entire time CO₂ has been measured. (3 points)

10. Bringing it all together: Comparing “young” carbon to “ancient” carbon:
Scientists can measure and track the amount of carbon dioxide human activities emit to the atmosphere. Our activities are like a carbon footprint: the carbon is what our activities “leave behind.” Compare the carbon footprint of using cow pie (biomass) for energy to using fossil fuels. Compare the origin of each energy source; is it “young” or “ancient?” With regard to the global carbon cycle, why does using young versus ancient carbon energy matter? (5 points)

Name: _____

Instructions: Read the assigned **Biofuel News Clips** (Student Edition, pages 8-10) and answer the related questions in the spaces provided.

Redesigning Life to Make Ethanol

1. Identify the trade-offs presented in the news clip.

2. Does the author suggest a cause for the issue presented?

3. Which decision category(ies) does the group feel this issue presents: environmental, social, political, or economic?

4. What is the “big idea” of this news clip?

Name: _____

It's Corn vs. Soybeans in a Biofuels Debate

5. Identify the trade-offs presented in the news clip.

6. Does the author suggest a cause for the issue presented?

7. Which decision category(ies) does the group feel this issue presents: environmental, social, political, or economic?

8. What is the “big idea” of this news clip?

Name: _____

Food Versus Fuel

9. Identify the trade-offs presented in the news clip.

10. Does the author suggest a cause for the issue presented?

11. Which decision category(ies) does the group feel this issue presents: environmental, social, political, or economic?

12. What is the “big idea” of this news clip?

Name: _____

The Promise of Biofuels—Hype or a Real Solution?

13. Identify the trade-offs presented in the news clip.

14. Does the author suggest a cause for the issue presented?

15. Which decision category(ies) does the group feel this issue presents: environmental, social, political, or economic?

16. What is the “big idea” of this news clip?

Name: _____

Instructions: Read the text below and answer the questions on the following page.

Is Ethanol Getting a Bum Rap?

By John Carey. *Business Week*, May 1, 2008.

There are grains of truth in this backlash, experts say. “There are bad biofuels and good biofuels,” says Daniel Sperling, director of the Institute of Transportation Studies at the University of California at Davis. Corn-based ethanol ranks as mediocre. Yet it is only a minor cause of high food prices, and better biofuels are on the horizon. The transition to these superior fuels will get a boost from policies now being developed, with California leading the way...

Instead of throwing out biofuels, the key is to speed up the transition from corn to crops that offer more benefits. There’s a surprisingly simple way to do it: Judge fuels on how much greenhouse gas is emitted during their entire production and transport, including emissions caused by converting land from food crops and other uses to fuel crops. Then ratchet down the amount of carbon that’s allowed...

This low-carbon fuel standard approach sets the market free to pick the best fuels to meet the standard. It immediately rules out biofuels from palm oil plantations carved out of the rainforest, for instance. It would also steer farmers away from corn because of corn ethanol’s lack of substantial greenhouse gas benefits. “Almost all of the pathways for using food crops to make energy will look very bad with a carbon metric,” explains UC Davis’ Sperling, who has worked on the approach. “The low-carbon fuel standard is one of the most outstanding policy instruments we have ever developed,” he says. Make this approach widespread, and it should be possible to have our biofuels and eat our crops, too.

This article originally appeared on www.businessweek.com on May 1, 2008. It is reprinted here with Business Week’s permission.

Carbon Footprint of Corn-Based Biofuel

Lesson 5 | page 2 of 2

Name: _____

Instructions: Answer the following questions in the spaces provided.

1. Identify the trade-offs presented in the news clip. (1 point)

2. What does the author suggest as a cause for the issue presented? (1 point)

3. Which decision category(ies) does this issue represent: environmental, social, political or economic? Identify one and use evidence from the article to justify your answer. (4 points)

4. What is the “big idea” of this news clip? (1 point)

5. People often use the analogy of “growing on trees” (or in this case, stalks) to say that something is free. In the case of biofuels, there is concern about all the costs involved. What are some of them? (3 points)



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