Exploring Climate Change

A comprehensive guide for learning about climate change through hands-on, critical thinking activities.

Grade Level:

Secondary

Subject Areas:

Science

Social Studies

Language Arts

Technology

NEED

National Energy Education Development Project

Teacher Advisory Board

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Energy Data Used in NEED Materials

NEED believes in providing teachers and students with the most recently reported, available, and accurate energy data. Most statistics and data contained within this guide are derived from the U.S. Energy Information Administration. Data is compiled and updated annually where available. Where annual updates are not available, the most current, complete data year available at the time of updates is accessed and printed in NEED materials. To further research energy data, visit the EIA website at www.eia.gov.

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Exploring Climate Change

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NEED gratefully acknowledges the work of the following individuals in creating the *Exploring Climate Change* curriculum:

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Developed in partnership with Princeton University's Carbon Mitigation Initiative.

CMI
Carbon Mitigation Initiative

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A Note from NEED

As America's policy-makers debate the development of public policy about carbon dioxide and climate change, it is important for the public to understand the technologies and techniques available to mitigate the release and impact of carbon dioxide. It is important to understand the science of climate and the way energy use and our consumer choices impact our environment, economics, and standard of living. The U.S. Department of Energy, the U.S. Environmental Protection Agency, the U.S. Department of Commerce, and other agencies have joined the nation's energy industry and the engineering and scientific community to find the best possible solutions to address climate change while reducing possible negative impacts on America's economy.

With this curriculum module, and other NEED activities, we hope to help students, teachers, and the local community understand more about energy, carbon dioxide, climate, and climate change. We hope that teachers and students will discuss and think about our use of energy and our personal energy choices with a global perspective too—recognizing that the choices made here in the United States have an impact on the global environment and that energy decisions made in other countries have an impact on us too. This curriculum module is meant to help distill a fairly complex and heavily politicized topic down to a level that our students can understand and comprehend—providing them with simulations and hands-on lessons and informational texts meant to provide a foundation for their learnings.

We are grateful to the Carbon Mitigation Initiative for their assistance with this project and we welcome feedback from teachers, students, and their families about the content and lessons found inside.

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Standards Correlation Information

www.NEED.org/curriculumcorrelations

Next Generation Science Standards

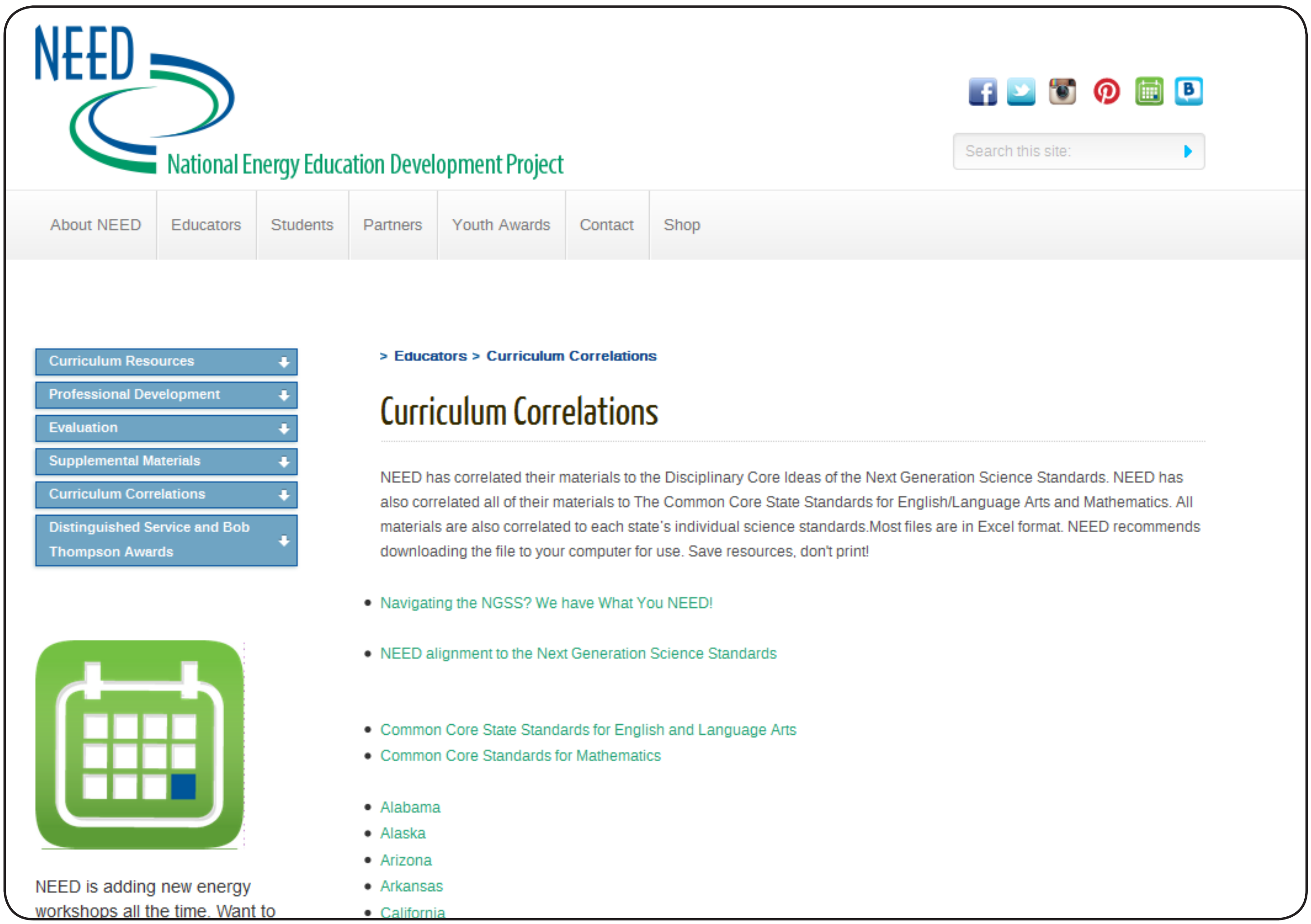
- This guide effectively supports many Next Generation Science Standards. This material can satisfy performance expectations, science and engineering practices, disciplinary core ideas, and cross cutting concepts within your required curriculum. For more details on these correlations, please visit NEED's curriculum correlations website.

Common Core State Standards

- This guide has been correlated to the Common Core State Standards in both language arts and mathematics. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED curriculum correlations website.

Individual State Science Standards

- This guide has been correlated to each state's individual science standards. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED website.



Exploring Climate Change Materials

The table below contains a list of materials needed for hands-on or laboratory activities. There are several activities that are not listed below that do not require materials other than pencils, paper, and copies. Many of the materials can be found in a common lab setting, or easily procured from a grocery or craft store. Refer to the activity instructions within the teacher guide for more specific instructions. Contact NEED if you have any questions or difficulty locating a certain item.

ACTIVITY	MATERIALS NEEDED
Greenhouse Gas Demonstration	▪Molecular model kit
Properties of CO_2	▪Plastic trash bags ▪Dry ice ▪Work gloves ▪Tongs ▪Clear plastic tubs or containers ▪Plastic trays ▪Bottles of bubbles ▪Bottles of water ▪Balloons ▪Pipe cleaners ▪Tea light candles ▪Matches ▪Plastic cups ▪Safety glasses
Greenhouse in a Beaker	▪600 mL Beakers ▪250 mL Flasks ▪Rubber stoppers with holes ▪3/16” Vinyl tubing, 60 cm lengths ▪Clip light with 75 watt bulb ▪Ruler ▪Probe thermometers ▪Masking tape ▪Alka-Seltzer® tablets ▪Safety glasses ▪Water
Carbon Cycle Simulation	▪2 Decks of playing cards
Carbon Footprints and Transportation	▪5 lb Bag of charcoal briquettes ▪Tall, white kitchen trash bag ▪Plastic grocery bag ▪Paper towles ▪All-purpose cleaner ▪8 ½”x 11” White paper
Climate Web	▪Ball of yarn or string ▪Scisssors ▪Hole punch ▪Cardstock
Electrical Devices and Their Impacts	▪Pluggable electrical devices

Teacher Guide

Background

Through reading and hands-on activities, this guide examines the science behind climate change, the relationship between energy use and climate change, and personal choices that can be made to address climate change. It is recommended that teachers become familiar with the information and activities included in this guide prior to classroom use.

Activity 1: Introduction to Climate Change

Objective

- Students will outline their current understanding of climate change.

Time

- One class period

Materials

- *Student Informational Text*, pages 20-34
- *Climate Change KWL Chart*, page 35

Procedure

1. Make copies of the informational text and KWL chart for the class.
2. Ask students, "What do you think you know about climate change?" Students should record their thinking on the *Climate Change KWL Chart*. Create a class chart on the board, if desired, to showcase student thoughts and initial discussion.
3. Encourage a class discussion about what students think they already know about climate change. Ask where students developed these ideas, and what questions they may have about climate change. List any questions in the KWL charts.
4. Have the students read the *Student Informational Text*. As they read, they should take notes and continue to add to their KWL charts.

Activity 2: Greenhouse Gas Demonstration

Background

Greenhouse gases are able to behave in the ways they do because of their molecular structure. In this activity, students will visually compare the bonding structure of atmospheric gases in order to begin to explain the impact the greenhouse gases have on the atmosphere.

Objectives

- Students will be able to identify carbon dioxide, methane, and water vapor as three of the major greenhouse gases.
- Students will be able to explain how greenhouse gases have an impact on the atmosphere.

Time

- 10 minutes, or more, depending on depth of discussion

Materials

- Molecular model kit with spring attachments to act as bonds

CONTINUED ON NEXT PAGE

Grade Level

- Secondary, grades 9–12

Time

- 10-15 class periods, depending on the activities implemented

Science Notebooks

This curriculum is designed to be used in conjunction with science notebooks. Experimental questions, procedures, sample data tables, and conclusion questions are provided. If you do not use notebooks in your classroom, students may require paper for recording data and conclusions. If you do use notebooks in your classroom, your students may choose to incorporate the activity sheets into their notebooks.

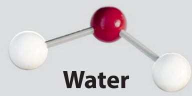
Additional Resources

Visit www.NEED.org for additional curriculum about, climate, energy sources as well as efficiency and conservation.

Recommended curriculum guides that will enhance your unit on climate change include:

- *Carbon Capture, Utilization, and Storage*
- *Energy Conservation Contract*
- *Great Energy Debate*
- *Learning and Conserving*
- *Mission Possible*
- *School Energy Survey*
- *Secondary Energy Infobook*

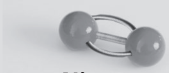
Greenhouse Gas Molecular Models



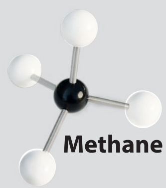
Water

Carbon Dioxide

Oxygen



Nitrogen



Methane

Dry Ice Safety

Carefully review the *Dry Ice Safety* sheet on page 18.

Dry ice can be obtained from many grocery stores. If you do not have access to dry ice, you can produce CO_2 gas by mixing equal parts baking soda and vinegar.

Preparation

- Make models of the compunds listed below. Sample pictures can be found on the left side of this page.
  - carbon dioxide (CO_2)
  - methane (CH_4)
  - water vapor (H_2O)
  - oxygen (O_2)
  - nitrogen (N_2)

✔ Procedure

1. Show students the models you made. Ask students to construct the models if you have the supplies. Explain the following:

   Carbon dioxide (CO_2), methane (CH_4), and water vapor (H_2O) are three of the major greenhouse gases. When the radiant energy from the sun travels through the Earth's atmosphere and strikes the surface of the Earth, some of that energy is radiated back as thermal energy and infrared energy that will leave the atmosphere, but much of it is absorbed by the greenhouse gases.

   The Earth's atmosphere is composed of 78.09 percent nitrogen gas (N_2), which has a triple bond between the nitrogen atoms, and 20.95 percent oxygen gas (O_2), which has a double bond between the oxygen atoms. The energy is stored within the movement of those molecules. Nitrogen gas and oxygen gas do not have a great deal of flexibility in the vibrations, rotation, expansion, and contraction of the bonds within the molecule.

2. Demonstrate to students how there is a great deal of flexibility in the bonds of water, methane, and carbon dioxide, while there is very little in the flexibility of the other gases in the atmosphere. While holding the central atom in the structures of water, carbon dioxide, and methane, apply a slight force to the atoms attached to the central atom and show how the bonds are able to move freely indicating the ability to store more energy than the bonds within nitrogen gas or oxygen gas.

Activity 3: Properties of CO_2

Background

In this activity, students will explore how CO_2 behaves in order to develop a better understanding of its role in our climate system.

Objective

- Students will be able to identify and describe the properties of carbon dioxide.

Time

- One class period

Materials

- Plastic trash bags
- 5-10 lbs. of Dry ice (keep in foam cooler until ready to use)
- Work gloves
- Tongs
- Large, clear containers or tubs
- Plastic trays
- Bottles of bubbles
- Bottles of water
- Balloons
- Pipe cleaners
- Tea light candles
- Matches
- Plastic cups
- Safety glasses
- *Properties of CO_2*, page 36
- *Dry Ice Safety*, page 18

CONTINUED ON NEXT PAGE

Preparation

- Make copies of the worksheet for students.
- You may conduct this activity as a demonstration, or gather enough containers, gloves, and tongs to allow small groups to work with the dry ice directly.
- Cover work surfaces with the plastic trash bags.
- Review the safety instructions for working with dry ice.

✔ Procedure

1. Project and discuss the safety instructions for working with dry ice with the class.
2. Place some dry ice on a plastic tray, place the tray of dry ice in the large container.
3. Explain that carbon dioxide (CO_2) is usually found in its gaseous form. However, it also can be found in a solid form and liquid form. Dry ice is frozen CO_2, or CO_2 in solid form.
4. Ask students, "What happens when frozen water warms up?" (It melts and turns into a liquid.) Next ask, "What do you think happens when frozen CO_2 warms up?" Have students record their predictions in their science notebooks. Have students observe the dry ice for a few minutes. Students should record observations using pictures and words in their science notebooks. Ask students to explain what they are seeing. Discuss that CO_2 does not exist as a liquid at standard atmospheric pressure. As frozen CO_2 thaws, or sublimes, it transforms directly into a gas. CO_2 exists as a liquid only under great pressure.
5. Pour water onto the dry ice until CO_2 gas fills the container. Blow bubbles into the large container. Have students record their observations on the *Properties of CO_2* worksheet, and explain what is happening. After students have had time to write down their own thoughts, explain that CO_2 is more dense than air. Since the bubbles are filled with air, they float on top of the CO_2 gas collected in the container.
6. Light a tea light candle. Using the plastic cup, collect some CO_2 gas from the dry ice container and pour it over the tea light. Using the *Properties of CO_2* worksheet, students should record what happens and explain what they saw. Explain that CO_2 displaces lighter oxygen. The CO_2 is heavier than air and pushes the oxygen away. The fire needs oxygen to continue burning so the fire is extinguished. This is why CO_2 is used in fire extinguishers.
7. Drop an ice cube sized piece of dry ice into a bottle of water. Place a balloon over the mouth of the water bottle. Use a pipe cleaner as a twist tie around the balloon, if needed. Students should record observations on their *Properties of CO_2* worksheets and explain what happened.

Note

When the effervescent tablets start to fizz and release carbon dioxide, the temperature of the gas coming from that reaction will be a little cooler than room temperature because the chemical reaction is endothermic. Therefore, students may see a slight dip in temperature before it starts to rise when they measure the CO_2 rich beaker. This is normal – the focus is more on how much the temperature changes rather than the actual maximum or minimum temperature attained.

During the experiment, the temperature in the CO_2 rich beaker will rise for several minutes. Once a temperature peak is reached, the temperature will start to drop again rapidly. This is because the supply of CO_2 in the small bottle has exhausted itself and because the natural convection currents in the beaker, driven by the heat from the light bulb, will disperse the CO_2.

Activity 4: Greenhouse in a Beaker

Background

In this activity, students will model the conditions that occur in a greenhouse, or in our atmosphere during the greenhouse effect.

Objective

- Students will be able to explain that carbon dioxide speeds up the transfer of thermal energy.

Time

- One class period

Materials *FOR EACH GROUP*

- 2 600 mL Beakers
- 1 250 mL Flask
- 1 Rubber stopper with hole
- 1 Vinyl tubing, 3/16" diameter, 60 cm long
- 1 Clip light
- 1 Ruler
- 1000-1100 lumen Bulb, equivalent to 75 watt incandescent
- 2 Probe thermometers
- 1 Small piece of masking tape
- 4 Alka-Seltzer® tablets
- Safety glasses
- Water (room temperature)
- *Greenhouse in a Beaker* worksheets, pages 37-38

Preparation

- Make copies of the worksheets for students.
- Gather materials for the activity and be sure enough outlet space for lamps is available.
- Divide students into groups.

Procedure

1. Introduce the investigation to students by asking, "If we add carbon dioxide to the air, what effect will this added CO_2 have on air temperature?"
2. Explain that students will be creating two models of our atmosphere using beakers to represent air in the atmosphere and a lamp to represent the sun. One beaker will contain a "normal" atmosphere. Carbon dioxide will be added to the second beaker, creating a CO_2-rich atmosphere. The CO_2 will be produced through a chemical reaction that occurs when Alka-Seltzer® is added to water. The active ingredients in Alka-Seltzer® are aspirin, citric acid, and sodium bicarbonate ($NaHCO_3$). When the tablet is placed in water, an acid-base reaction involving sodium bicarbonate and the citric acid takes place yielding sodium citrate, water, and carbon dioxide.

$$3NaHCO_3 + C_6H_8O_7 \longrightarrow Na_3C_6H_5O_7 + 3H_20 + 3CO_2(g)$$

3. Assign students to their groups. Pass out the *Greenhouse in a Beaker* worksheets.
4. Circulate around the room assisting groups as needed.

Extension

- Ask students what variables they can change in the investigation. Let students design new investigations, and in their conclusions, have them correlate their changes to actual conditions that may change in Earth's climate system.

Activity 5: Carbon Cycle Simulation

Background

Carbon cycles naturally through reservoirs or sinks in the environment over time. What happens to the carbon cycle when there is an excess of carbon in one or more of the reservoirs? This simulation will help students to envision how carbon naturally cycles in the carbon cycle and how the carbon cycle is affected with an excess of carbon.

This simulation uses both pre-Industrial Revolution and post-Industrial Revolution information to showcase the natural cycle and the cycle with excess carbon.

Objectives

- Students will be able to describe the basic ways that carbon cycles throughout the Earth's systems.
- Students will be able to compare how carbon cycled through the Earth's systems prior to the Industrial Revolution and after the Industrial Revolution.

Time

- One to two class periods

Materials

- Two decks of playing cards, divided by suit
- *Student Informational Text*, pages 20-34
- *Carbon Reservoir Comparison* chart, page 39
- Reservoir posters, pages 40-43
- Reservoir instruction sheets, pages 44-52
- 2 Copies of the *Carbon Tracking Sheet* for each student, page 53
- Carbon Cycle PowerPoint (optional)

Pre-Industrial Round Preparation

- Make copies of student worksheets and posters.
- Hang up the reservoir posters and place the Pre-Industrial Round instruction sheets around the classroom, as shown in the diagram on page 12.
- Place a full suit of cards at each of the eight reservoirs.
- Download the optional PowerPoint from www.NEED.org to display and discuss the roles of the reservoirs in the game.

✔ Pre-Industrial Round Procedure

1. Pass out the *Carbon Reservoir Comparison* chart and have students use the informational text to compare the four major carbon reservoirs. Review the information as a class. Use the optional PowerPoint to review student work.
2. Explain to students that in this activity, they will become carbon atoms and model the possible different forms carbon can become as it travels between reservoirs.
3. Use the chart on page 13 to divide your students among the reservoirs. The natural exchange of carbon between the lithosphere and atmosphere pre-Industrial Revolution was negligible, so the lithosphere is not used in this round.
4. Pass out one *Carbon Tracking Sheet* to each student. Students will record which reservoirs they travel to in this round.
5. Assign students to their first reservoir using the chart on page 13. Students record the necessary information about their reservoir and carbon form on their *Carbon Tracking Sheet*. Students should be able to count how many people are at the reservoir and record the number on his/her sheet.

CONTINUED ON NEXT PAGE

Online Resources

Samples of the reservoir posters and instruction sheets are on pages 40-52. To download full size color copies of the posters visit www.NEED.org.

Note

If you do not have enough students to make up the minimum number in either the Pre-Industrial or Present Day Rounds, you can create "proxy carbons" to fill the needed spots. A simple sheet of paper marked "proxy carbon" will do. Assign one or two students to be "proxy managers" who will be responsible for drawing the cards for the proxy carbons, and moving them where they need to go.

6. Explain to students that you will go through the first round together and they should not pull cards until instructed. Students should not change reservoirs until given a signal to move. At that time, everyone who is changing reservoirs based on the card they pulled will move.
7. Instruct students to each choose a card and use the directions on the sheet to determine who leaves the reservoir and who stays. Students return the cards to the original pile.
8. Signal students to change reservoirs. Once everyone has arrived where they need to be, the group again counts how many people are at the reservoir and students write down the necessary information about the reservoir and carbon form on their worksheet.
9. Repeat steps seven and eight until you have completed 10 cycles in the Pre-Industrial Round.
10. Bring the students together and discuss what they noticed about carbon movement, the forms carbon comes in, and about the amount of carbon in each reservoir.

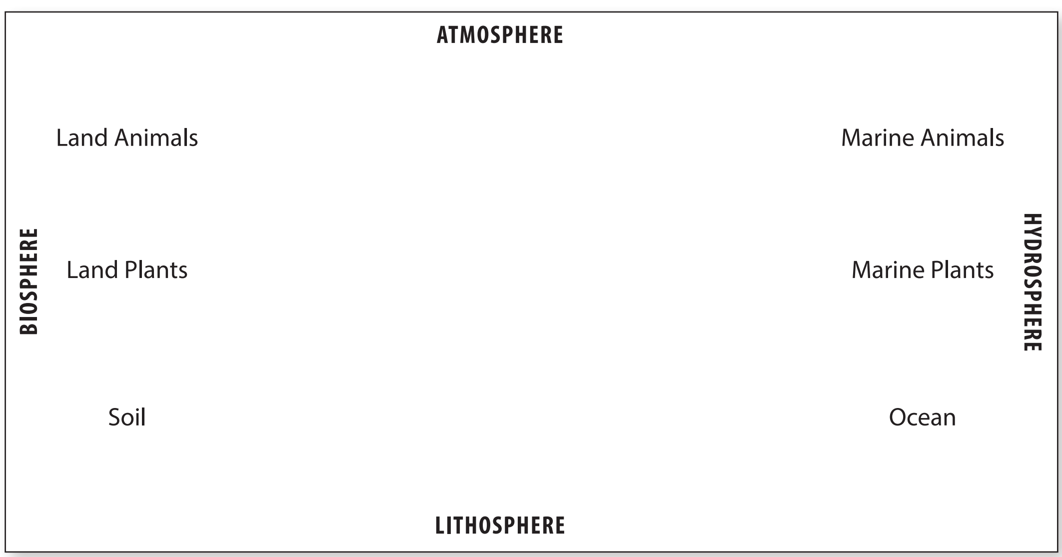
Present-Day Round Preparation

1. Place the Present Day Round Atmosphere and Lithosphere instruction sheets, pages 45 and 52, and the Lithosphere poster, page 43, out with the rest of the materials from the Pre-Industrial Round, as shown in the diagram below.

✔ Present-Day Round Procedure

1. Pass out a new *Carbon Tracking Sheet* to each student.
2. Assign students reservoirs using the Present-Day Round table on page 13.
3. Follow the same directions as the Pre-Industrial Round and complete 10 cycles in the Present-Day Round.
4. When complete, discuss with the students the differences between the Pre-Industrial Round and the Present-Day Round. Use the data collected on the posters to graph the movement between the reservoirs. What conclusions can students make about carbon cycling based on the data?

Suggested Placement of Reservoir Posters



Number of Students in Each Reservoir

PRE-INDUSTRIAL ROUND TOTAL NUMBER OF STUDENTS	ATMOSPHERE CO_2 GAS	BIOSPHERE LAND PLANT	BIOSPHERE LAND ANIMAL	BIOSPHERE SOIL	LITHOSPHERE FOSSIL FUEL	HYDROSPHERE OCEAN	HYDROSPHERE MARINE PLANT	HYDROSPHERE MARINE ANIMAL
18	5	3	2	1	0	4	2	1
19	5	3	2	1	0	5	2	1
20	5	4	2	1	0	5	2	1
21	6	4	2	1	0	5	2	1
22	6	4	2	1	0	5	3	1
23	6	4	3	1	0	5	3	1
24	7	4	3	1	0	5	3	1
25	7	4	3	1	0	5	3	2
26	7	4	3	2	0	5	3	2
27	8	4	3	2	0	5	3	2
28	8	4	3	2	0	6	3	2
29	8	5	3	2	0	6	3	2
30	9	5	3	2	0	6	3	2
31	9	5	3	2	0	6	4	2
32	9	5	4	2	0	6	4	2

PRESENT-DAY ROUND TOTAL NUMBER OF STUDENTS	ATMOSPHERE CO_2 GAS	BIOSPHERE LAND PLANT	BIOSPHERE LAND ANIMAL	BIOSPHERE SOIL	LITHOSPHERE FOSSIL FUEL	HYDROSPHERE OCEAN	HYDROSPHERE MARINE PLANT	HYDROSPHERE MARINE ANIMAL
28	5	3	2	1	10	4	2	1
29	5	3	2	1	10	5	2	1
30	5	4	2	1	10	5	2	1
31	6	4	2	1	10	5	2	1
32	6	4	2	1	10	5	3	1

Activity 6: Carbon Footprints and Transportation

Background

Transportation plays a sizeable role in our greenhouse gas emissions with transportation contributing roughly 33% of CO_2 emissions. Electrciity generation is the other major contributor to CO_2 emissions, with almost 31%. A person's transportation and day to day electrical consumption descisions make up a big part of their carbon footprint, due to the burning of fossil fuels to supply electricity and transportation fuels. In this activity, students will consider their own choices in transportation and can calculate their overall carbon footprint in order to consider their personal impacts and make informed changes.

Objectives

- Students will be able to explain individual carbon footprints.
- Students will be able to list means for reducing carbon footprints.

Time

- One to two class periods

Materials

- 5 lb. Bag of charcoal briquettes
- 1 Tall, white kitchen trash bag
- 1 Plastic grocery bag
- Paper towels
- All-purpose cleaner
- White 8 ½" x 11" paper
- *Road Trip* worksheet, page 54
- *Carbon Footprint* worksheet, page 55

Preparation

- Prior to this activity, have students research uses for CO_2 as homework. Encourage students to find ways CO_2 is used in residential, industrial, and medical settings. Students should make a list and bring the list with them to class.
- Make copies of the worksheets for students.

✔Procedure

1. Break students into small groups to brainstorm a list of uses for CO_2 based on their findings from the homework assignment.
2. Based on the previous activities, students should understand that CO_2 is released into the atmosphere during fossil fuel combustion. This includes combustion from fossil-fueled power plants generating electricity, from manufacturing processes, and from the burning of fossil fuels as a fuel in vehicles.
3. Review that CO_2 is usually found in a gas form. It is colorless and transparent to light. Even though we know CO_2 impacts the environment, we do not always think about it because we cannot see it. Show students the bag of charcoal briquettes. The briquettes are made almost completely of carbon. The bag of briquettes will represent the amount of carbon in one gallon of gas. The average gallon of gasoline contains about five pounds of carbon. There are typically about 100 briquettes in the bag. By dividing five pounds of carbon by 100 briquettes, that means there are about 0.05 pounds of carbon per briquette.
4. Discuss how many miles each student drives (or is driven) to and from school each day. Calculate how many briquettes represent the carbon dioxide emissions from their transportation to and from school. Use the bags to cover the workspace and hold individual briquettes. Students can use the *Carbon Footprint* worksheet for calculations.
5. Pass out the *Road Trip* worksheet. Students will plan a road trip and calculate the CO_2 emitted on their trip.

   NOTE: If students do not know the fuel economy of their vehicles, direct them to the website www.fueleconomy.gov. Selecting a vehicle can also be assigned as homework the night before.
6. When students are done calculating their *Road Trip* carbon footprint, give them each a separate piece of paper. Have students write a letter or article citing at least three suggestions for reducing carbon footprints. Students should also reflect on why it is important to understand their carbon footprint and why it matters.

Online Extensions

- Go to www.NEED.org to download the *Transportation Fuels Infobook* and to find more activities relating to transportation.
- Students can calculate their family's household emissions using the Environmental Protection Agency's Emissions Calculator at www3.epa.gov/carbon-footprint-calculator/. It will be most accurate if students have an energy bill from home they can reference. Other calculators that include items like diet and recycling also are easily searched online.

Activity 7: Climate Web

Background

This activity helps students to visualize climate as a system with many items feeding into it and relying on its function.

Objectives

- Students will be able to identify components in the climate system and describe their functions.
- Students will be able to describe the connections between each component in the climate system.

Time

- One class period

Materials

- Ball of yarn or string
- Scissors
- Hole punch
- Cardstock
- Climate web hang tags, pages 56-60
- *Climate Systems* worksheet, page 61

Preparation

- Copy the climate hang tags onto cardstock for durability and laminate for reuse.
- Cut apart the hang tags and use a single hole punch to make two holes in the top corner of each.
- Lace one length of yarn or string through each hang tag and tie off, creating a necklace.
- Make copies of the *Climate Systems* worksheet for students.

Procedure

1. Hand out the hang tag necklaces and ask students to read the backs of their cards aloud so other students in the group know the roles in the activity. Give students a chance to ask any questions they have about what is written on their cards.
2. Direct students to put on their hang tags and stand in a circle.
3. Hand the ball of yarn to one of the students. Explain that he or she should look around the circle and identify another student representing a component of the system that is related to his or her role. Some of these relationships are spelled out in the descriptions on the backs of the hang tags.
4. Holding on to the end of the yarn, the first student passes the ball of yarn to that student, explaining how that part of the system relates to him or her. That student then repeats the process, holding onto the yarn and passing the ball on.

CONTINUED ON NEXT PAGE

Classroom Management Note

When handing out hang tags to students, some have descriptions that allow for easy identification of related components in the climate system. It may be wise to strategically assign cards to your students based on their prior knowledge.

5. Continue passing the yarn around until everyone has their hands on the yarn. While connections can be made between each component, students may have trouble seeing all of them. Because of this, it is acceptable to pass to a student a second time before the yarn has made it all the way around the circle. In the end, the students will have created a web made of yarn connecting all of them.
6. Now choose a student to give a tug on the string. Explain that this tug represents an influence (positive or negative) being exerted by that part of the system. For instance, the person wearing the 'Coal' tag might give a tug, and you would say, "Coal is mined and processed for electrical energy. This process emits particles into the air and coal is a nonrenewable resource." Or 'Solar Energy' might give a tug and you would say, "Increasing the use of solar PV reduces our CO_2 emissions from generating electricity."
7. Ask students to raise their hands if they feel a pull when the string is tugged. Ask students why their component might be influenced by the original component that tugged on the string. Discuss the connections and why some students might feel stronger pulls than others.
8. Repeat this several times with different students tugging. For each tug, describe how that component is influencing the system.
9. Pass out the *Climate Systems* worksheet. Ask students to describe how the system is dependent on all of the components. Students should be able to explain that a change in one part of the system can affect all other parts of the system.

Activity 8: Electrical Devices and Their Impacts

Background

Electric Nameplates

Every appliance and machine in the United States that uses electricity has a nameplate with the voltage required and the wattage. Sometimes, the current is listed instead of the voltage. If any two of the three measurements are listed, the third can be determined using the following formula: **wattage = current x voltage**.

Often, you will see the letters UL on the nameplate. The UL mark means that samples of the product have been tested to recognized safety standards and have been found to be reasonably free from fire, electric shock, and related safety hazards.

Using the data on the nameplate, the amount of time the appliance is used, and the cost of electricity, you can determine the cost of operating the appliance. To determine the cost to operate an appliance for one hour, use this formula: **cost/h = wattage (kW) x cost/kWh**.

Environmental Effects

Carbon dioxide (CO_2) is a greenhouse gas. Human activities have dramatically increased its concentration in the atmosphere. Since the Industrial Revolution, the level of CO_2 in the atmosphere has increased by more than 45 percent. Generating electricity accounts for a large portion of CO_2 emissions in the U.S. Some electricity generation—such as hydropower, solar, wind, geothermal, and nuclear—does not produce carbon dioxide because no fuel is burned.

A large amount of the nation's electricity (about 33 percent), however, comes from burning coal. Another 36 percent comes from burning natural gas, petroleum, and biomass. There is a direct correlation between the amount of electricity we use and the amount of CO_2 emitted into the atmosphere. The rule of thumb is that generating a kilowatt-hour (kWh) of electricity produces 1.5 pounds of CO_2, which is emitted into the atmosphere.

Objectives

- Students will be able to describe the energy requirements of using certain electrical appliances.
- Students will be able to calculate the cost of using electrical appliances.

Time

- One to three class periods

Materials

- Pluggable electrical devices (classroom or home)
- *Electric Nameplates*, page 62
- *Cost of Using Machines,* page 63
- *Environmental Impact*, page 64

CONTINUED ON NEXT PAGE

✔ Procedure

1. Make copies of the worksheets for students.
2. Discuss electric nameplates with the students. Show an example of one using an item in the classroom. Explain what they are and why they are used.
3. Allow students to find nameplates on devices in the classroom, or brought from home. Have students record their data on the *Electric Nameplates* worksheet.
4. Have students calculate the cost of using machines using the formulas and data table on the *Cost of Using Machines* worksheet.
5. Students should then calculate the environmental impact of using electrical machines and devices using the information on the *Environmental Impact* worksheet.
6. Discuss current machine use with the class and how to reduce energy use. Discuss monetary impacts as well as environmental implications.

Activity 9: Wedge Challenge

✪ Objectives

- Students will understand the technologies currently available that can substantially cut carbon emissions.
- Students will develop critical reasoning skills as they create a portfolio of strategies to cut greenhouse gas emissions.

🕒 Time

- Four class periods

✔ Procedure

For complete directions and all materials, please see the *Wedge Challenge* guide and activity sheets on pages 65-90.

☑ Evaluation

Following the completion of your unit, evaluate the unit with your students using the *Evaluation Form* on page 94 and return it to The NEED Project.

Dry Ice Safety

What is Dry Ice?

Dry ice is frozen carbon dioxide. Unlike most solids, it does not melt into a liquid, but instead changes directly into a gas. This process is called sublimation. The temperature of dry ice is around -109° F! It sublimates very quickly so if you need dry ice for an experiment or project, buy it as close as possible to the time you need it.

Dry Ice Safety Rules

1. Students: Never use dry ice without adult supervision. Dry ice can cause serious injury if not used carefully!
2. Never store dry ice in an airtight container. As the dry ice undergoes sublimation from a solid directly into a gas, the gas will build up in the container until it bursts. Sharp pieces of container will go flying all over the place. Make sure your container is ventilated. The best place to store dry ice is in a foam chest with a loose fitting lid.
3. Do not touch dry ice with your skin! Use tongs, insulated (thick) gloves, or an oven mitt. Since the temperature of dry ice is so cold, it can cause severe frostbite. If you suspect you have frostbite, seek medical help immediately.
4. Never eat or swallow dry ice! Again, the temperature of dry ice is very, very cold. If you swallow dry ice, seek medical help immediately.
5. Never lay down in, or place small children or pets in homemade clouds. The clouds are made of carbon dioxide gas. People and pets could suffocate if they breathe in too much gas.
6. Never place dry ice in an unventilated room or car. If you are traveling with dry ice in the car, crack a window open. The same rule applies if you are in a small room, crack a window open. You do not want too much carbon dioxide gas to build up around you.
7. Always wear safety glasses when doing experiments with dry ice.
8. Do not place dry ice directly on counter tops. The cold temperature could cause the surface to crack.
9. Leave the area immediately if you start to have difficulty catching your breath. This is a sign that you have inhaled in too much carbon dioxide gas.
10. Do not store dry ice in your freezer. It will cause your freezer to become too cold and your freezer may shut off. However, if you lose power for an extended period of time, dry ice is the best way to keep things cold in an ice chest or cooler.

Disposing of Dry Ice

To dispose of dry ice, place in a well ventilated container and take it outside where small children and pets cannot reach it. Simply let it sublimate away.

Data: NOAA and NWS

Climate Change Resources

American Association for the Advancement of Science
http://www.aaas.org/news/press_room/climate_change/

Carbon Dioxide Information Analysis Center
http://cdiac.ess-dive.lbl.gov

Earth Vision Institute, Getting The Picture
www.gettingthepicture.info

Intergovernmental Panel on Climate Change
www.ipcc.ch

International Energy Agency
www.iea.org

NASA's Eyes on the Earth
http://climate.nasa.gov

National Center for Atmospheric Research - Kids' Crossing
http://eo.ucar.edu/kids/green/index.htm

National Oceanic and Atmospheric Administration
www.noaa.gov/climate.html

U.S. Department of Energy
www.energy.gov/science-innovation/climate-change
https://energy.gov/eere/office-energy-efficiency-renewable-energy
www.afdc.energy.gov/

U.S. Energy Information Administration
www.eia.gov
www.eia.gov/environment.html
www.eia.gov/kids
www.eia.gov/energyexplained/

U.S. Environmental Protection Agency
www.epa.gov/energy
www.epa.gov/statelocalenergy

United Nations Environment Programme
www.unep.org/climatechange

United Nations Environment Programme, GRID-Arendal
www.grida.no

United States Global Change Research Program
http://globalchange.gov

Exploring Climate Change

Student Informational Text

What is Energy?

Energy does things for us. It moves cars along the road and boats on the water. It bakes a cake in the oven and keeps ice frozen in the freezer. It plays our favorite songs and lights our homes at night so that we can read good books. Energy helps our bodies grow and our minds think. Energy is a changing, doing, moving, working thing.

Energy is defined as the ability to produce change or do work, and that work can be divided into several main tasks we easily recognize:

- Energy produces light.
- Energy produces heat.
- Energy produces motion.
- Energy produces sound.
- Energy produces growth.
- Energy powers technology.

Energy at a Glance, 2015

	2014	2015
World Population	7,178,722,893	7,245,299,845
U.S. Population	318,857,056	321,418,820
World Energy Production	539.5 Q	546.7 Q
U.S. Energy Production	87.398 Q	88.024 Q
• Renewables	9.6923 Q	9.466 Q
• Nonrenewables	77.706 Q	78.558 Q
World Energy Consumption	537.36 Q	542.49 Q
U.S. Energy Consumption	99.868 Q	97.344 Q
• Renewables	9.656 Q	9.450 Q
• Nonrenewables	90.212 Q	87.667 Q*

Q = Quad (10^{15} Btu), see Measuring Energy on page 22.

Data: Energy Information Administration

*Totals may not equal sum of parts due to rounding of figures by EIA.

Forms of Energy

There are many forms of energy, but they all fall into two categories–potential or kinetic.

POTENTIAL ENERGY

Potential energy is stored energy or the energy of position. There are several forms of potential energy, including:

- **Chemical energy** is energy stored in the bonds of atoms and molecules. It is the energy that holds these particles together. **Biomass**, petroleum, natural gas, and propane are examples of stored chemical energy.

  During photosynthesis, sunlight gives plants the energy they need to build complex chemical **compounds**, like glucose. When these compounds are later broken down, the stored chemical energy is released as heat, light, motion, and sound.
- **Elastic energy** is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of items with elastic energy.
- **Nuclear energy** is energy stored in the nucleus of an atom—the energy that holds the nucleus together. The energy can be released when the nuclei are combined or split apart. Nuclear power plants split the nuclei of uranium atoms in a process called **fission**. The sun combines the nuclei of hydrogen atoms into helium atoms in a process called **fusion**. In both fission and fusion, mass is converted into energy, according to Einstein's Theory, $E = mc^2$.
- **Gravitational potential energy** is the energy of position or place. A rock resting at the top of a hill contains gravitational potential energy. Hydropower, such as water in a reservoir behind a dam, is an example of gravitational potential energy.

KINETIC ENERGY

Kinetic energy is motion—the motion of waves, electrons, atoms, molecules, substances, and objects. Forms of kinetic energy include:

- **Electrical energy** is the movement of electrons. Everything is made of tiny particles called atoms. Atoms are made of even smaller particles called electrons, protons, and neutrons. Applying a force can make some of the electrons move. Electrons moving through a wire are called **electricity**. Lightning is another example of electrical energy.
- **Radiant energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Light is one type of radiant energy. Solar energy is an example of radiant energy.
- **Thermal energy**, or heat, is the internal energy in substances—the vibration and movement of atoms and molecules within substances. The faster molecules and atoms vibrate and move within substances, the more energy they possess and the hotter they become. Geothermal energy is an example of thermal energy.
- **Motion energy** is the movement of objects and substances from one place to another. According to Newton's Laws of Motion, objects and substances move when an unbalanced force is applied. Wind is an example of motion energy.
- **Sound energy** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate. The energy is transferred through the substance in a wave.

Conservation of Energy

Your parents may tell you to conserve energy. "Turn out the lights," they say. But to scientists, **conservation** of energy means something quite different. The law of conservation of energy says energy is neither created nor destroyed.

When we use energy, we do not use it completely—we just change its form. That's really what we mean when we say we are using energy. We change one form of energy into another. A car engine burns gasoline, converting the chemical energy in the gasoline into motion energy that makes the car move. Old-fashioned windmills changed the kinetic energy of the wind into motion energy to grind grain. Solar cells change radiant energy into electrical energy.

Energy can change form, but the total quantity of energy in the universe remains the same. The only exception to this law is when a small amount of matter is converted into energy during nuclear fusion and fission.

Efficiency

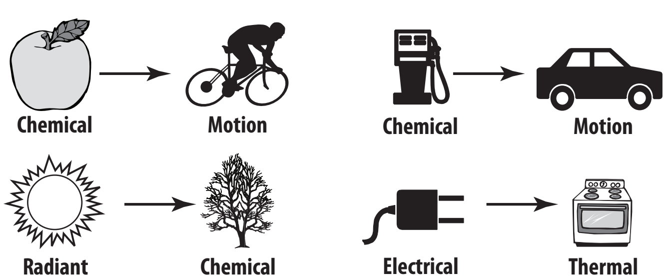
Energy efficiency is how much useful energy you can get out of a system. In theory, a 100 percent energy efficient machine would change all of the energy put in it into useful work. Converting one form of energy into another form always involves a loss of usable energy, usually in the form of heat.

In fact, most **energy transformations** are not very efficient. The human body is no exception. Your body is like a machine, and the fuel for your "machine" is food. Food gives us the energy to move, breathe, and think. Your body is very inefficient at converting food into useful work. Most chemical energy from the food you eat is released as thermal energy.

An incandescent light bulb isn't efficient either. This type of light bulb converts ten percent of the electrical energy into light and the rest (90 percent) is converted into thermal energy (heat). That's why these bulbs are so hot to the touch.

Most electric power plants are about 35 percent efficient. It takes three units of fuel to make one unit of electricity. Most of the other energy is lost as waste heat. The heat dissipates into the environment where we can no longer use it as a practical source of energy.

Energy Transformations

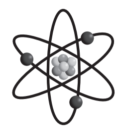


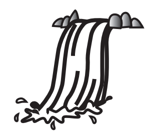
Forms of Energy

POTENTIAL

Chemical Energy 

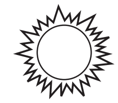
Elastic Energy 

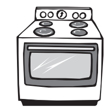
Nuclear Energy 

Gravitational Potential Energy 

KINETIC

Electrical Energy 

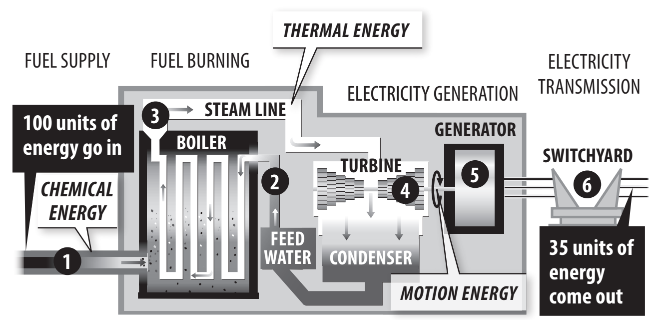
Radiant Energy 

Thermal Energy 

Motion Energy 

Sound Energy 

Efficiency of a Thermal Power Plant



How a Thermal Power Plant Works

1. Fuel is fed into a boiler, where it is burned to release thermal energy.
2. Water is piped into the boiler and heated, turning it into steam.
3. The steam travels at high pressure through a steam line.
4. The high pressure steam turns a turbine, which spins a shaft.
5. Inside the generator, the shaft spins coils of copper wire inside a ring of magnets. This creates an electric field, producing electricity.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

Sources of Energy

People have always used energy to do work for them. Thousands of years ago, early humans burned wood to provide light, heat their living spaces, and cook their food. Later, people used the wind to move their boats from place to place. A hundred years ago, people began using falling water to make electricity.

Today, people use more energy than ever from a variety of sources for a multitude of tasks and our lives are undoubtedly better for it. Our homes are comfortable and full of useful and entertaining electrical devices. We communicate instantaneously in many ways. We live longer, healthier lives. We travel the world, or at least see it on television and the internet.

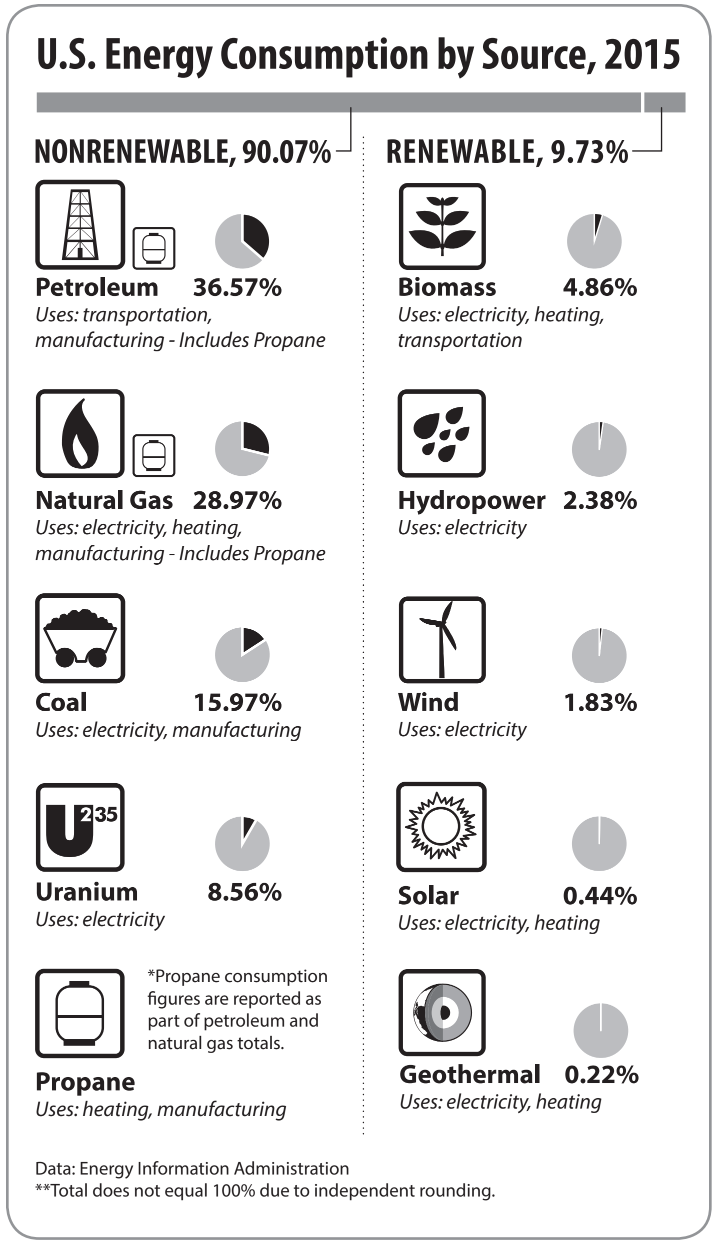
The ten major energy sources we use today are classified into two broad groups—nonrenewable and renewable.

Nonrenewable energy sources include coal, petroleum, natural gas, propane, and uranium. They are used to generate electricity, to heat our homes, to move our cars, and to manufacture products from candy bars to cell phones.

These energy sources are called nonrenewable because they cannot be replenished in a short period of time. Petroleum, for example, was formed hundreds of millions of years ago from the remains of ancient sea life, so we can't make more quickly. We could run out of economically recoverable nonrenewable resources some day.

Renewable energy sources include biomass, geothermal, hydropower, solar, and wind. They are called renewable energy sources because their supplies are replenished in a short time. Day after day, the sun shines, the wind blows, the plants grow, and the rivers flow. We use renewable energy sources mainly to make electricity.

Is electricity a renewable or nonrenewable source of energy? The answer is neither. Electricity is different from the other energy sources because it is a **secondary energy source**. That means we have to use another energy source to make it. In the United States, coal is the number one fuel for generating electricity.



Measuring Energy

"You can't compare apples and oranges," the old saying goes. That holds true for energy sources. We buy gasoline in gallons, wood in cords, and natural gas in cubic feet. How can we compare them? With **British thermal units** (Btu), that's how. The energy contained in gasoline, wood, or other energy sources can be measured by the amount of thermal energy in Btu it can produce.

One Btu is the amount of thermal energy needed to raise the temperature of one pound of water one degree Fahrenheit. A single Btu is quite small. A wooden kitchen match, if allowed to burn completely, would give off about one Btu of energy. One ounce of gasoline contains almost 1,000 Btu of energy.

Every day the average American uses about 829,178 Btu. We use the term quad (Q) to measure very large quantities of energy. A quad is one quadrillion (1,000,000,000,000,000 or 10^{15}) Btu. The United States uses about one quad of energy approximately every 3.75 days. In 2007, the U.S. consumed 101.296 quads of energy, an all-time high.

Energy Use

Imagine how much energy you use every day. You wake up to an electric alarm clock and charge your cell phone. You take a shower with water warmed by a hot water heater using electricity or natural gas.

You listen to music on your smart phone as you catch the bus to school. And that's just some of the energy you use to get you through the first part of your day!

Every day, the average American uses about as much energy as is stored in a little more than seven gallons of gasoline. That's every person, every day. Over a course of one year, the sum of this energy is equal to a little more than 2,500 gallons of gasoline per person. This use of energy is called **energy consumption**.

Energy Users

The U.S. Department of Energy uses categories to classify energy users—residential, commercial, industrial, electric power, and transportation. These categories are called the sectors of the economy.

▪ Residential/Commercial

Residences are people's homes. Commercial buildings include office buildings, hospitals, stores, restaurants, and schools. Residential and commercial energy use are often lumped together because homes and businesses use energy in the same ways—for heating, air conditioning, water heating, lighting, and operating appliances.

The residential/commercial sector of the economy consumed 10.76 percent of the total energy supply in 2015, with a total of 10.48 quads. The residential sector consumed 6.37 quads and the commercial sector consumed 4.11 quads.

▪ Industrial

The industrial sector includes manufacturing, construction, mining, farming, fishing, and forestry. This sector consumed 21.44 quads of energy in 2015, which accounted for 22.02 percent of total consumption.

▪ Electric Power

The electric power sector includes electricity generation facilities and power plants. All of the other sectors consume electricity generated by the electric power sector. The electric power sector consumed 38.92 percent of the total energy supply in 2015, more than any of the other sectors, with a total of 37.89 quads.

▪ Transportation

The transportation sector refers to energy consumption by cars, buses, trucks, trains, ships, and airplanes. In 2015, the U.S. consumed 27.52 quads of energy for transportation, which accounted for 28.27 percent of total consumption. 92.44 percent of this energy was from petroleum products such as gasoline, diesel, and jet fuel.

Energy Use and Prices

Several decades ago, in 1973, Americans faced a major oil price shock due to an **oil embargo**. People didn't know how the country would react. How would Americans adjust to skyrocketing energy prices? How would manufacturers and industries respond? We didn't know the answers.

Now we know that Americans tend to use less energy when energy prices are high. We have the statistics to prove it. When energy prices increased sharply in the early 1970s, energy use dropped, creating a gap between actual energy use and how much the experts had thought Americans would be using.

The same thing happened when energy prices shot up again in 1979, 1980, and more recently in 2008—people used less energy. When prices started to drop, energy use began to increase.

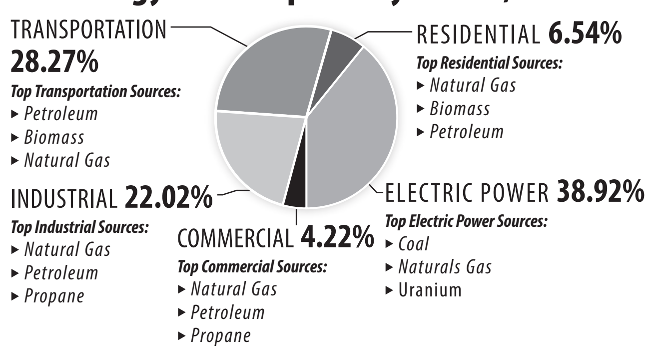
We don't want to simplify energy demand too much. The price of energy is not the only factor in the equation. Other factors that affect how much energy we use include the public's concern for the environment and new technologies that can improve the efficiency and performance of automobiles and appliances.

Most reductions in energy consumption in recent years are the result of improved technologies in industry, vehicles, and appliances. Without these energy conservation and efficiency technologies, we would be using much more energy today.

In 2015, the United States used 29 percent more energy than it did in 1973. That might sound like a lot, but the population has increased by over 50 percent and the nation's **gross domestic product** was 2.67 times that of 1973.

You may wonder why the 1970s are important—it was so long ago. However, the energy crisis during this decade taught us a valuable lesson. If every person in the United States today consumed energy at the rate we did in the 1970s, we would be using much more energy than we are—perhaps as much as double the amount. Energy efficiency technologies have made a huge impact on overall consumption since the energy crisis of 1973.

U.S. Energy Consumption by Sector, 2015



The residential, commercial, and industrial sectors use electricity. This graph depicts their energy source consumption outside of electricity.

Data: Energy Information Administration

*Total does not equal 100% due to independent rounding.

Introduction to Climate Change

A Changing Climate

Since its formation, the climate of the Earth has been in a constant state of change. Many factors have altered the climate, including the Earth's orbit and changing proximity to the sun, as well as the amount of heat-trapping **gases** in the **atmosphere**.

Human societies have evolved during an extended period of favorable climatic conditions. In fact, some researchers believe that a period of favorable climate was the primary factor that allowed the rise of civilization.

Over the past several decades, scientists have compiled an increasing amount of data indicating that, for the first time in Earth's history, the activities of one **species**—*homo sapiens*—are altering the climate. Research shows a significant increase in the **concentration** of heat-trapping gases, especially **carbon dioxide** (CO_2), in the Earth's atmosphere since the beginning of the Industrial Revolution. A rise in global temperatures corresponds to the rise in carbon dioxide.

There are many complex forces, both natural and man-made, at work governing our climate. Should we be concerned if human activities are changing the climate? How might a changing climate affect us?

Weather and Climate

Climate and weather are not the same thing; the difference is simply a matter of time. **Weather** describes the conditions in the atmosphere over a short period of time, and is usually described in terms of its effects on human activities. Weather forecasts are focused on temperature, humidity, precipitation, atmospheric pressure, and wind conditions that occur over a time span of days.

Scientists usually look at averages over at least 30-year time spans to determine long term trends and describe **climate**. Russian Wladimir Köppen developed the most famous climate classification chart in 1884. Using annual and monthly temperatures, precipitation patterns, and native vegetation, Köppen categorized the Earth into five different climate groups. He refined it over his lifetime with the help of German scientist Rudolf Geiger. Their work is often called the Köppen-Geiger Classification System.

Climate Groups

A. **Tropical Moist Climates:** all months have average temperatures above 18° Celsius or 64.6° Fahrenheit.

B. **Dry Climates:** with deficient precipitation during most of the year.

C. **Moist Mid-Latitude Climates with Mild Winters**

D. **Moist Mid-Latitude Climates with Cold Winters**

E. **Polar Climates:** with extremely cold winters and summers.

Climatologists have analyzed multiple sources to put together a history of Earth's climate. By looking at **ice cores**, boreholes, tree rings, glacier lengths, pollen remains, ocean sediments, and by studying Earth's orbit, they have determined that the climate naturally changes over time. There are multiple variables that affect Earth's natural climate patterns.

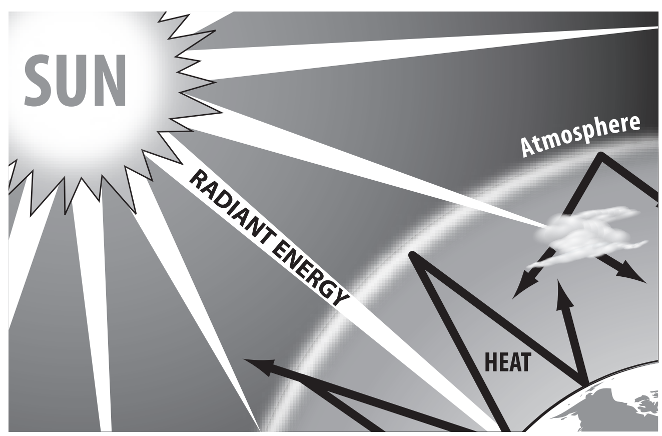
▪ Earth's Reflectivity

The reflectivity of the Earth's surface plays an important part in climate patterns. We all know that if you want to stay cooler on a hot, sunny day, you should wear light colors—especially white. We are kept cooler because more of the radiant energy from the sun that strikes us reflects off instead of being transformed into thermal energy. Earth works the same way. Some of the sun's radiant energy striking Earth is reflected back into space. The amount of reflection that takes place off any given point of the Earth's surface varies widely. A dark surface like a parking lot or a body of water will reflect less than 10 percent of the light, while snow and ice can reflect 90 percent. Earth's atmosphere reflects 26 percent of the incoming radiation.The ability of a surface to reflect light is called its **albedo**.

During the ice ages when the initial decrease in solar **radiation** allowed more snow to accumulate, this high albedo surface reflected more solar radiation, thus keeping the ground and the air cooler. Scientists call this a 'positive feedback loop'. As this loop continued, it allowed snow and ice to accumulate for thousands of years until the **Milankovitch Cycles** increased solar radiation enough to promote warming of the climate.

The Greenhouse Effect

A natural heat-trapping process



Radiant energy (light rays) shines on the Earth. Some radiant energy reaches the atmosphere and is reflected back into space. Some radiant energy is absorbed by the atmosphere and is transformed into heat (dark arrows).

Half of the radiant energy that is directed at Earth passes through the atmosphere and reaches the Earth, where it is transformed into heat.

The Earth absorbs some of this heat.

Most of the heat flows back into the air. The atmosphere traps the heat.

Very little of the heat escapes back into space.

The trapped heat flows back to the Earth.

Now, the reverse is occurring. As the climate has warmed, there has been a decrease in snow and ice coverage. Those surfaces that previously had a high albedo are revealing low albedo surfaces, such as soil and water, as they melt. This feedback loop is predicted to increase the rate at which the Earth warms.

▪ Earth's Orbit

Serbian mathematician Mulitin Milanković (1879-1958) was the first to mathematically explain how the Earth's orientation to and orbit around the sun change regularly.

Milanković's calculations explained three Earth movements—Earth's orbit (**eccentricity**), angle of tilt (**obliquity**), and wobble on its axis (**precession**). These changes occur in cycles, called Milankovitch Cycles, which last thousands of years. These cycles affect the distribution of sunlight over the Earth's surface and the intensity of the seasons, and very slightly affect the total amount of radiation received. Milanković theorized that it is these cycles that are the driving force of ice ages.

The Earth is currently in an interglacial period. According to Milanković's theory, and if human factors are not taken into account, this period of relative warmth is predicted to last at least another 50,000 years. Then, as the Milankovitch Cycles change, conditions favorable for another ice age would be created.

▪ Sun's Intensity

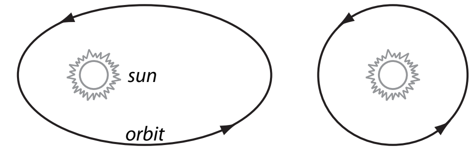
It is also believed that variations within the sun can affect the intensity of the sunlight reaching Earth's surface. Low solar activity will cause cooling, while stronger solar activity can cause warming. Between the years 1350 and 1900, the Northern Hemisphere experienced cooler temperatures, approximately 1-2°C lower than present temperatures, which caused a time known as "The Little Ice Age." NASA research attributes the cooler temperatures in part to reduced solar intensity.

▪ Volcanic Eruptions

Short term climate changes can occur with large, or multiple, volcanic eruptions. When a volcano erupts, aerosols and carbon dioxide are added to the air. **Aerosols** contribute to short term cooling because they block the sun's radiant energy. Aerosols do not stay in the atmosphere long, which is why their impact is only short term. Indonesia is a volcanic island nation. It is believed that some of its larger eruptions, Mount Toba 71,000 years ago, Tambora in 1815, and Krakatau in 1883, all contributed to world-wide cooling in the years immediately following the eruptions. Other **volcanism** along the Pacific Ring of Fire and Greenland may have also led to temporary cooler temperatures within longer climate cycles.

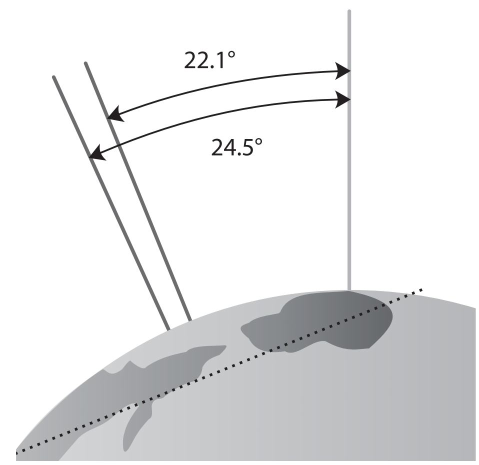
When volcanoes erupt, additional CO_2 is sent into the atmosphere. One theory is that numerous volcanic eruptions raised CO_2 levels enough to raise temperatures periodically over the last 400 million years. However, research into the relationship of volcanic CO_2 to climate change has not shown a strong connection between the two.

Eccentricity



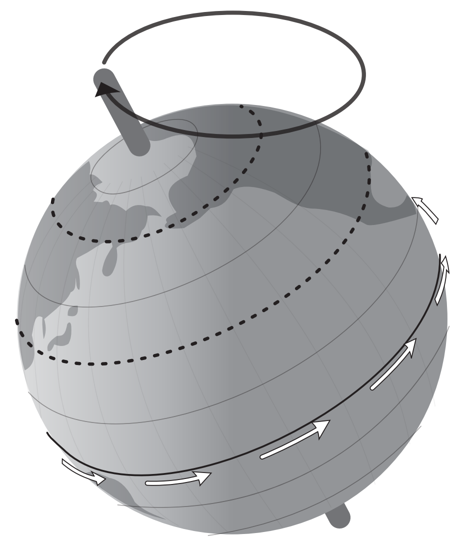
Eccentricity is the shape of the Earth's orbit around the sun. This constantly fluctuating, orbital shape ranges between more and less elliptical on a cycle of about 100,000 years.

Obliquity



Range of the tilt of Earth's axis of rotation (obliquity). Present tilt is 23.5º.

Precession



Precession is the change in direction of the Earth's axis of rotation caused primarily by the gravitational pull of the sun and moon.

Natural Climate Change and Climate Change From Human Activity

It is estimated that ten thousand years ago there were five million humans on Earth. One thousand years ago the population had reached 254-245 million, and by 1900 the world's population had reached 1.6 billion. Today, there are more than seven billion people on Earth. Natural climate cycles provided warmer climates and allowed the human population to grow rapidly.

As some climatologists continued to analyze and record temperatures they found a rising temperature trend, one that was moving faster than they would have anticipated based on normal Earth cycles. Most scientists believe that the way humans are interacting with the Earth in their everyday lives is causing a faster than natural climate change.

Earth's Systems

The Earth can be divided into four systems—the **lithosphere**, the **hydrosphere**, the **biosphere**, and the atmosphere. Each of these systems has a specific role in keeping the Earth going and in the storage of carbon. They each play a part in affecting the weather, and in turn, the climate. These systems, and **cycles** within the systems, replenish the Earth with water, supply energy, and create a climate that is able to sustain plant, animal, and human life. Each system has many inputs and outputs, which can affect the overall Earth system. Some of these systems are affected by inputs and outputs that have been naturally transpiring for thousands of years. Some of these systems are affected by inputs specifically from human activity.

▪ The Lithosphere

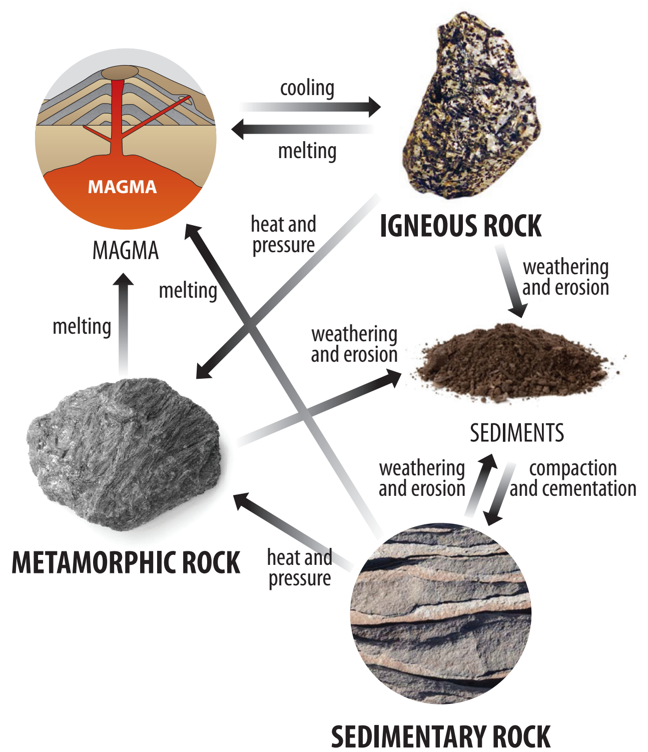
Rocks, minerals, volcanoes, and **fossil fuels** make up the lithosphere. The major cycle within the lithosphere is the rock cycle. Slowly, over long periods of time, rocks can be transformed from sedimentary rocks, to metamorphic rocks, to igneous rocks. By far, most of the carbon on Earth is found in the lithosphere—over 50,000 times as much as that found in the atmosphere. Found primarily in rocks and minerals, carbon mainly takes the form of carbonates (combinations of **carbon**, calcium, and oxygen) and is found in rocks such as limestone and shale. Sedimentary rocks contain fossils of plants and animals. As the sedimentary rocks go through the rock cycle, these fossils are subjected to pressure and heat. Under these conditions some of the fossils transform into fossil fuels—petroleum, coal, and natural gas, which are all combinations of hydrogen and carbon called **hydrocarbons**.

▪ The Hydrosphere

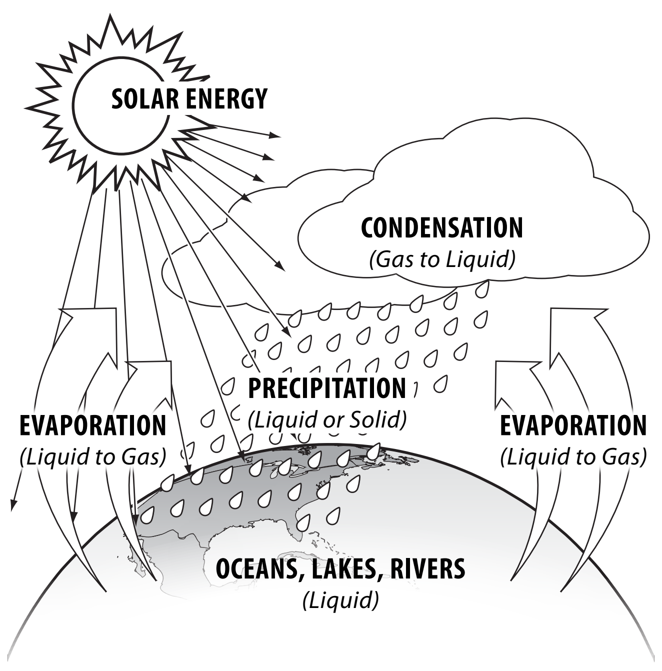
Over seventy percent of the Earth is covered by bodies of water—oceans, lakes, rivers, etc. Any form of water is included in the hydrosphere. Water is constantly on the move, whether flowing in a river, in the changing tides and currents of an ocean, or through the water cycle.

Water vapor is released to the atmosphere from all surface water sources, primarily the oceans, but also lakes and other fresh and salt water bodies. When water vapor in the atmosphere is cooled, and when enough water vapor has been condensed, it falls back to the Earth as **precipitation** in the form of rain, snow, sleet, or hail. When water vapor condenses closer to the Earth, precipitation is found in the form of dew or fog. Precipitation can fall onto land (the lithosphere) or back into a body of water, staying in the hydrosphere.

Lithosphere: The Rock Cycle



Hydrosphere: The Water Cycle



While a very small percentage of the carbon in the hydrosphere is found in the fresh water sources (mostly in groundwater), the majority of carbon in the hydrosphere is found in the world's oceans. This carbon is found mainly in the form of carbonates. It is also found in the upper levels of the ocean where dissolved carbon dioxide is utilized by plants for photosynthesis. The carbon contained in marine and plant animals contributes to the carbon content of the hydrosphere.

The Biosphere

Plants, animals, fungi, and microorganisms are examples of parts of the biosphere. Included in this system are things that are living, were alive a short time ago, or are derived from living organisms. Cycles within the biosphere include the life cycle for both plants and animals. The food chain is also an important event taking place within the biosphere. Cycles from outside the biosphere are crucial to the continuation of the biosphere cycles. These cycles include the water cycle, nitrogen cycle, **carbon cycle**, and the flow of energy throughout them. The biosphere contains vast amounts of carbon. It is found in the form of **carbohydrates** and proteins primarily in both living and decaying organisms.

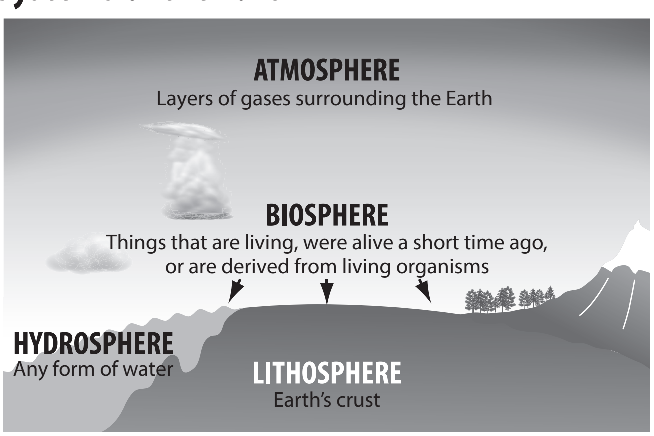
The Atmosphere

The atmosphere interacts with all of the other systems. The atmosphere acts like the glass of a greenhouse building; it surrounds the Earth and keeps it warm, sustaining an environment that promotes life. Composed of layers of gases surrounding the Earth, the atmosphere is made of roughly 78 percent nitrogen, 21 percent oxygen, and one percent argon. The remaining one percent is made of a mixture of carbon dioxide (CO_2), **methane** (CH_4), **nitrous oxide** (N_20), water vapor, and trace amounts of other gases. It is CO_2, CH_4, and water vapor that have proven to be very efficient at trapping heat. Collectively these and several other gases are known as the **greenhouse gases** (GHGs). The atmosphere contains the smallest amount of carbon compared to the other Earth systems. Here, carbon primarily takes the form of CO_2, but also as CH_4. The atmosphere is the only Earth system that exchanges significant amounts of carbon directly with all of the others.

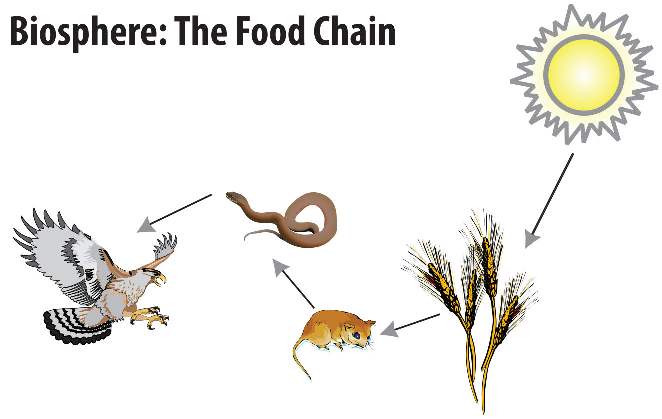
GHGs are molecules with three or more component atoms, which have unevenly distributed electrons and are efficient at trapping thermal energy. They are able to absorb **infrared radiation** and then re-radiate it, most often to another greenhouse gas molecule. Eventually the heat flows to the upper atmosphere and outer space, but the gases slow down this heat transfer, acting like a layer of insulation. While oxygen and nitrogen make up 98 percent of the atmosphere, they have evenly distributed electrons and are not affected by thermal energy in the same way that GHGs are.

Even though GHGs compose less than one percent of the atmosphere, their heat trapping capabilities are powerful and small changes in their concentration appear to be making a significant difference to Earth's climate.

Systems of the Earth



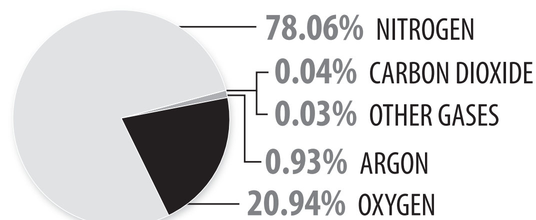
Biosphere: The Food Chain



The sun is part of the food chain. Plants turn sunlight directly into food, but animals cannot.

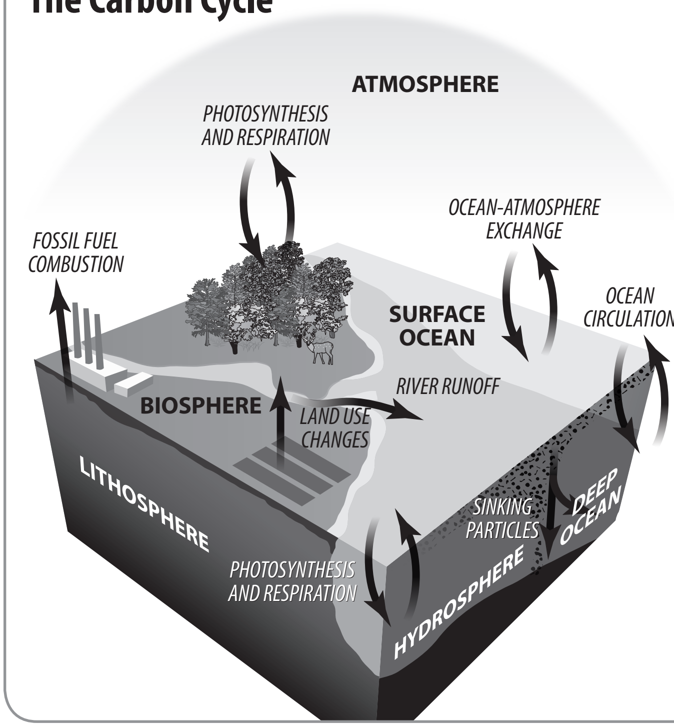
A mouse gets its energy from the plant, which got its energy from the sun. A snake gets its energy by eating the mouse. A hawk gets its energy by eating the snake. Food chains are energy flows.

Atmospheric Composition, Dry Air



Water vapor varies widely from region to region and according to the time of year. The average is about one percent and can be anywhere from trace amounts to four percent of atmospheric volume.

The Carbon Cycle



A Closer Look at Greenhouse Gases

When energy is sent from the sun, the shorter wavelengths, such as ultraviolet and visible light, pass through the atmosphere and strike the surface of the Earth. The atmosphere and objects on the Earth's surface absorb this radiation. Much of this radiation is transformed into thermal energy and the infrared energy is radiated back from the surface of the Earth and some of it into space. The reason that much of the heat is contained within our atmosphere is due to the properties of greenhouse gases. The atmosphere is composed mostly of nitrogen and oxygen. The bonding structures of nitrogen gas (triple bonded) and oxygen (double bonded) do not have a great deal of flexibility with the bending and stretching of their bonds. The greenhouse gases, such as carbon dioxide, methane, water vapor, and nitrous oxide, have a great deal of flexibility in the vibrating, stretching, and bending of their bonds. Therefore, as the molecules are exposed to infrared radiation, the bonds within these molecules have a great deal of potential to absorb that energy. This increases the kinetic energy of these molecules and raises the internal heat in the molecules, which can then be transmitted to other atmospheric gases to increase the temperature of the atmosphere, and therefore the temperature of the surface of the Earth.

▪ Carbon Dioxide

Just over eighty percent of U.S. greenhouse gas emissions come in the form of carbon dioxide. Historically, natural levels of CO_2 in the atmosphere have been governed by the cycling of carbon that occurs between Earth's four systems. Today only five percent of atmospheric CO_2 levels are attributed to natural processes. Ninety-five percent of CO_2 emissions come from human activity—the **combustion** of fossil fuels in electricity generation, transportation, industrial, commercial, and residential uses.

▪ Methane

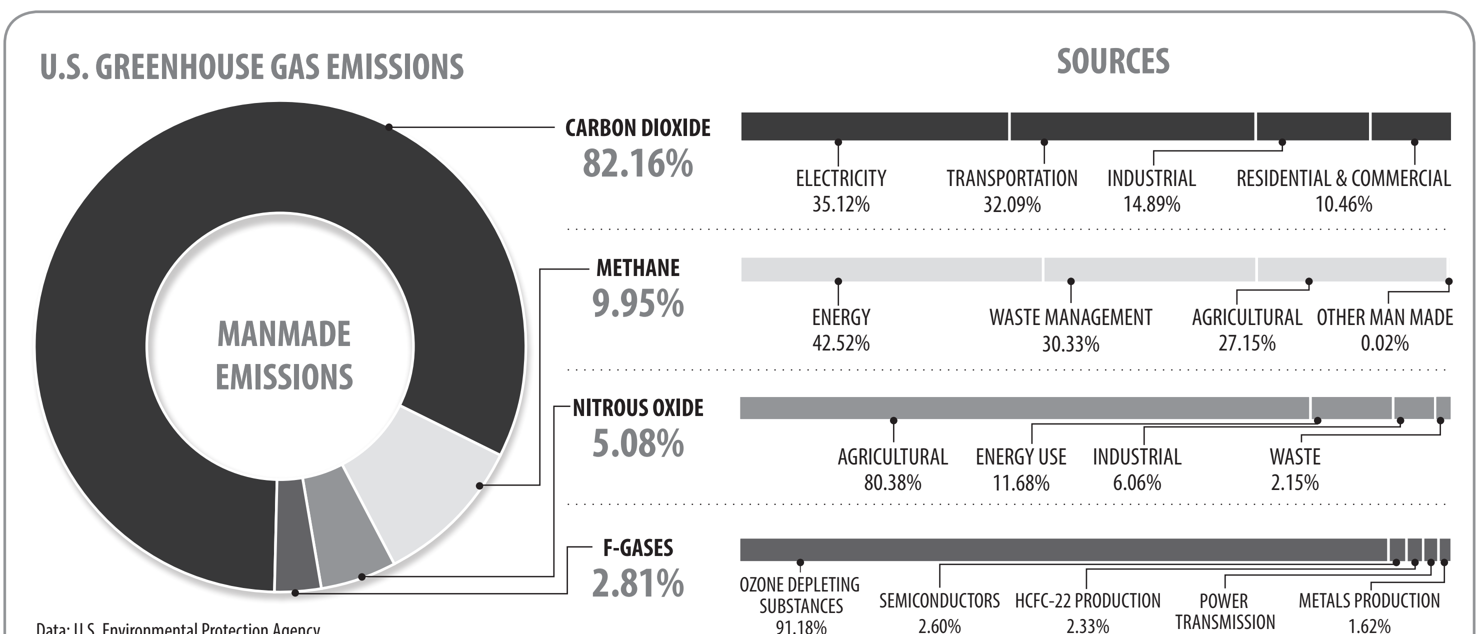
Methane is not as abundant in the atmosphere as CO_2; it makes up about 10 percent of greenhouse gas emissions, but it is 20 times more effective at trapping heat than CO_2. However, methane has a short lifespan, breaking down in the atmosphere after approximately 12 years. In the last 250 years, CH_4 concentrations have risen 160 percent. Methane emissions come from enteric fermentation (the digestive process of livestock), decomposition of waste in landfills, solid waste, producing and burning fossil fuels, biomass burning, and rice cultivation.

▪ Nitrous Oxide

Nitrous oxide makes up about 5 percent of the U.S. greenhouse gas emissions, yet N_2O is over 300 times more powerful than carbon dioxide at trapping heat. N_2O is naturally released into the atmosphere from natural processes in the soil and ocean. However, current agricultural practices release high levels of N_2O from the soil, as does fuel combustion in motor vehicles.

▪ Water Vapor

Climatologists who have been analyzing greenhouse gases have found that water vapor is the most abundant GHG, accounting for two-thirds of all heat trapped in the atmosphere. Constantly moving between the hydrosphere, atmosphere, and biosphere, water vapor is a key player in the climate picture. Some scientists believe that rising atmospheric temperatures around the world may allow the atmosphere to hold more water vapor, which might, in turn, lead to more warming. However, water vapor levels have remained relatively constant through history, so it does not appear that increased water vapor is responsible for the changing climate.



Data: U.S. Environmental Protection Agency
*F-gases include HCFCs, PFCs, and SF_6, which are used in many different industrial applications, including refrigerants, propellants, and tracer chemicals.

Fossil Fuels Past and Present

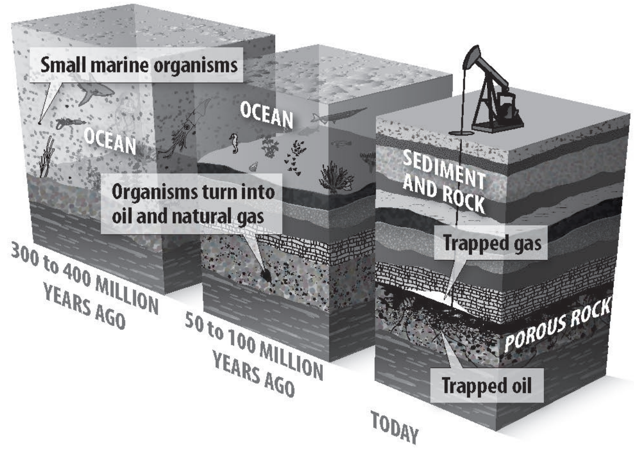
359 million to 299 million years ago the world had a more tropical and mild year-round climate than it does today. Called the Carboniferous Period, the climate during this time enabled the growth of expansive swamps and tropical forests filled with towering trees, massive ferns, large horsetails, and other leafy vegetation.

These plants all relied on the sun's radiant energy and the process of photosynthesis to grow and flourish. Through photosynthesis, the plants use radiant energy from the sun to turn the carbon dioxide in the air and water molecules into chemical energy, which they store in their leaves, fruits, stalks, and roots in the form of carbohydrates. Plants release oxygen back into the air. There were so many plants during this period that large amounts of carbon dioxide were removed from the atmosphere and large amounts of oxygen were released back into the atmosphere. During the Carboniferous Period, oxygen made up around 35 percent of the atmosphere.

Plants that grew in the swamps also died in the swamps. When the plants died the unused carbohydrates largely remained in the plant. Plant remains were covered by sand and clay from an ever changing landscape. It formed a layer of peat, which kept getting pushed farther and farther down as the land above shifted. Over millions of years the pressure and heat from the Earth squeezed out all of the water from the peat and it turned into coal.

Similarly, oil and natural gas are the result of small plants and animals that lived in the sea and died hundreds of millions of years ago, before dinosaurs lived. Remains of the plants and animals fell to the sea floor and over time were buried under sediment and other rock. The heat and pressure turned the carbon into oil and natural gas.

How Petroleum and Natural Gas Were Formed



Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of sediment and rock.

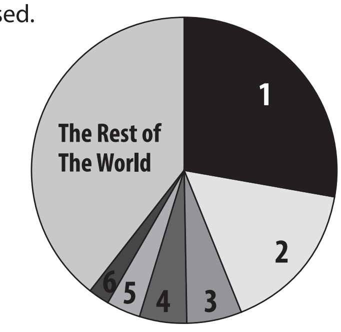
Over hundreds of millions of years, the remains were burried deeper and deeper. The enormous heat and pressure turned them into oil and gas.

Today, we drill down through the layers of sedimentary rock to reach the rock formations that contain oil and gas deposits.

For many millions of years the carbon dioxide found in fossil fuels was trapped deep below the ground. Levels of carbon dioxide in the atmosphere fluctuated with Earth's natural processes of carbon cycling. Humans relied on solar energy or burning biomass, usually

Global Greenhouse Gas Emissions

Carbon dioxide accounts for more than 80 percent of all global greenhouse gas emissions, mainly due to the increased use of fossil fuels. Since the Industrial Revolution, the concentration of all greenhouse gasses has increased. Only a few countries produce most of the global carbon dioxide emissions each year.



RANK/COUNTRY	CO_2 EMISSIONS MILLION METRIC TONS	SHARE OF GLOBAL EMISSIONS
1. China	9,376.68	**27.80%**
2. United States	5,507.80	**16.33%**
3. India	1,895.36	**5.62%**
4. Russia	1,756.00	**5.21%**
5. Japan	1,177.08	**3.49%**
6. Germany	756.17	**2.24%**
The Rest of the World		***39.32%***
World Total =	***33,732.83***	

Data: Energy Information Administration

wood, for cooking, heating, and lighting. The relatively small influx of carbon dioxide into the atmosphere from the burning of wood does not seem to have had a significant impact on Earth's overall climate.

When the Industrial Revolution began in the mid 1700s, energy use began to change dramatically. In less than 200 years, coal, petroleum, and natural gas became the primary sources for industry, electricity, and transportation.

Effects of Climate Change

The use of fossil fuels allows humans to see at night, to stay comfortable in hot weather and cold, to cook food efficiently, to keep food for longer periods of time, and to travel quickly from place to place. Fossil fuels allow us to work, move goods and products to market, and to make technology work. The CO_2 concentration in the atmosphere prior to the Industrial Revolution was about 280 ppm (parts per million). Currently, CO_2 concentration is about 410 ppm, more than a 45 percent increase. As already discussed, levels of methane, nitrous oxide, and other greenhouse gases have also increased. Scientists are studying what effects these higher levels of gases are currently having on our climate and what the future implications may be.

▪ Temperature

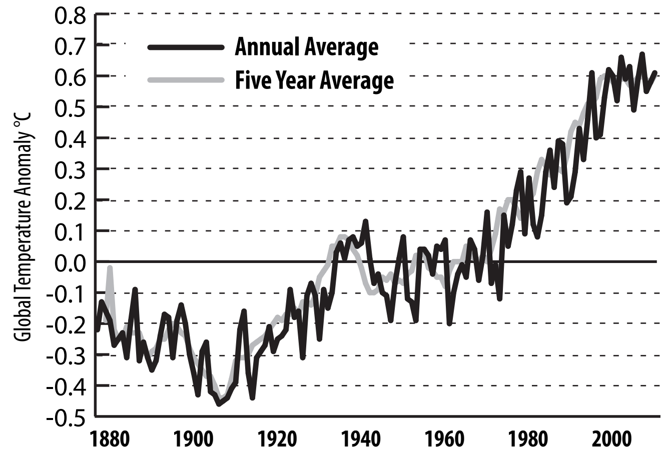
In 2013, the **Intergovernmental** Panel on Climate Change (IPCC) concluded, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." In the years since, many more studies have been conducted by climatologists. They have collected more data and have analyzed the predictions made in 2013.

Using data collected both by using satellites and by personal presence in multiple locations, scientists have confirmed earlier reports that average temperatures over land and water are increasing. Land surface air temperatures have increased over 1.3°C since 1880. The rate of change since 1979 has been more than double the rate of change in the previous 100 years. In other words, temperatures over land are increasing, and are doing so at a higher and higher rate. Temperatures on the surface of the seas have been increasing, too. Since 1979 scientists have measured a 0.6°C increase in average ocean surface temperature.

Why are land temperatures increasing more than water temperatures? For one, water has the capacity to absorb more thermal energy than land. Thus, the same amount of energy added to land will result in a greater temperature change than would be seen in an equal mass of water. Additionally, the Earth's surface is about ¾ water and only ¼ land. Most solar energy reaching the surface of the Earth will reach the oceans rather than land. As a result, most of the sun's incoming solar energy warms the water rather than the land on Earth.

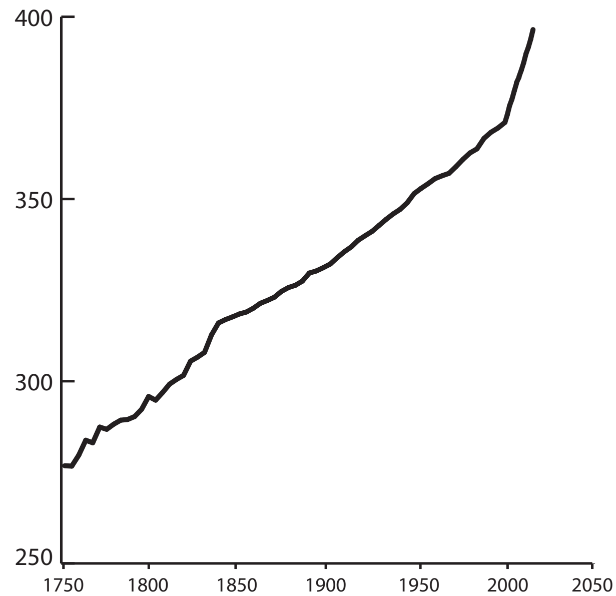
Not only are overall average, year-round temperatures increasing, but also the average high temperatures (day time) and low temperatures (night time) are increasing. There have been significantly more heat waves in regions between the tropics and the Arctic and Antarctic Circles, known as temperate regions. Most of the United States lies in this temperate zone.

Global Temperature Change Since 1880



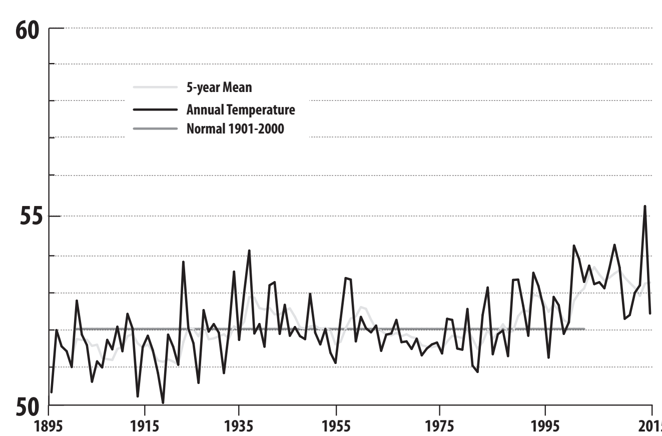
Data: NASA

CO2 Levels 1744-Present



Data: Earth System Research Laboratory

Contiguous U.S. Annual Average Temperatures 1895-2013



Data: NOAA

In the United States, the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center statistics show that the average contiguous U.S. temperature is trending above normal, increasing 0.13°F each ten years since 1895, and 0.48°F per decade since 1979. All of the climate regions have been increasing in temperature since 1895 except for the Southeast, but since 1979 this region has shown temperature increases, too.

Increasing temperatures worldwide are making significant **impacts** in all areas, but are most marked in the cryosphere, or portion of the Earth that is frozen most or all of the time. In these regions, sea ice, glacier volume, land ice sheet size, and permafrost area have all decreased dramatically since the Industrial Revolution. According to the IPCC's Fifth Assessment Report, released in 2013, sea ice has decreased 3.5-4.1% each decade between 1979 and 2012. Multi-year ice, or ice that has been in continuous existence for more than one freezing season, has decreased by 13.5% per decade.

Glaciers are shrinking worldwide at a rate that has been raising sea levels 0.83 mm/year since 2005, and this loss is likely irreversible. When it was established in 1910, Glacier National Park in Montana had nearly 150 glaciers. In 2010, the number of remaining glaciers larger than 25 acres had been reduced to 25. Scientists believe that by 2020 all of the glaciers in this park may be gone. In May, 2014, scientists from the University of California-Irvine and NASA's Jet Propulsion Laboratory concluded that six glaciers in Antarctica were degrading more rapidly than previously expected, and that the loss of the glaciers is inevitable. Ice sheets in Greenland have been decreasing in mass, too. Between 1992 and 2001, 34 **gigatons** (one billion tons, Gt) of ice were lost each year. However, between 2002 and 2011, 215 Gt were lost each year. More than 2/3 of the Earth's fresh water is found in glaciers and ice sheets.

Permafrost in northern Russia, the southern limit of continuous permafrost, has migrated northward by 50 km. As permafrost thaws, it releases additional carbon dioxide and methane that would otherwise have remained trapped in the frozen ground. However, it is difficult to identify exactly the amount of these two gases that have been released into the atmosphere as a result of permafrost thawing. Structures and roadways that were built on land that was previously permafrost and now undergo seasonal thawing can become unstable as the ground beneath them melts.

Sea Level Changes

In the last century, data shows that the sea level has risen worldwide approximately 12-22 centimeters. The rate and amount the sea level has changed varies greatly depending on the region. In some regions levels are quickly rising, while in others sea levels are actually falling. Previously, monitoring devices were lacking outside of the U.S., Europe, and Japan, making it difficult to gather data about long-term trends in regional sea level rise. However, a number of methods using satellite data and mathematical modeling have concluded that sea levels rose between 1900 and 2010 at a rate of 1.7 mm/year, and between 1993 and 2010 at a rate of 3.2 mm/year. While scientists do not know all of the reasons behind the increased levels, they have a high confidence that they are indeed rising, and are confident in some of the primary factors.

First, the oceans are warming. From the surface to a depth of 700 meters, global ocean temperature has risen by 0.10°C between 1961 and 2010. When matter undergoes a temperature change its volume changes. In this case, when water is heated, the particles are more active and maintain a greater average separation, causing the water to expand and the sea level to rise. The IPCC believes that **thermal expansion** accounts for about 57 percent of sea level rise each year.

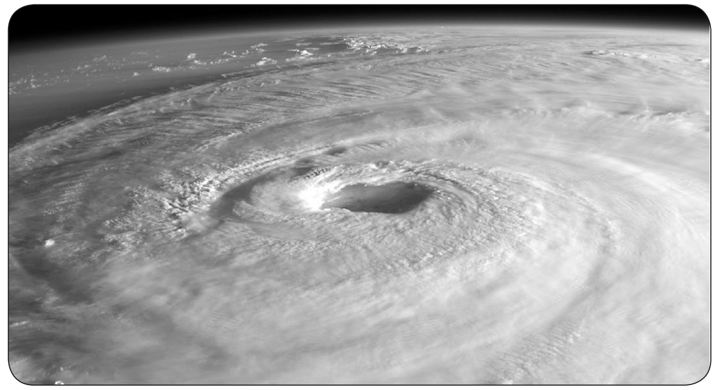


Image courtesy of NASA

This photo from the International Space Station shows Hurricane Isabel, a 2003 Category 5 storm. Climatologists believe climate change may generate more intense storms.

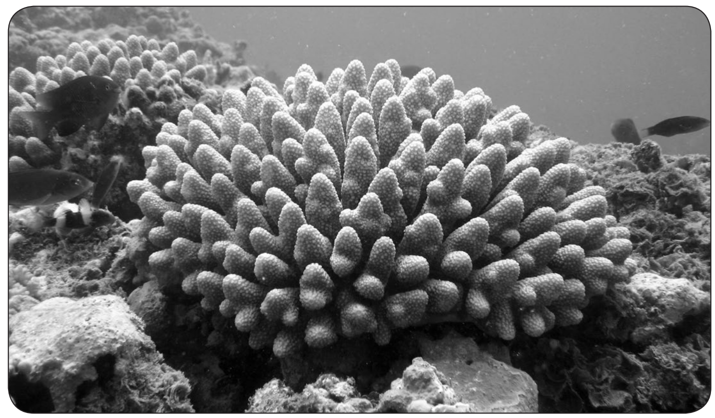


Image courtesy of National Oceanographic and Atmospheric Administration

Ocean acidification can affect the formation of coral and other marine calcifiers.

Melting of glaciers and ice sheets is another major factor contributing to rising sea levels. As stated before, much of the loss of ice in Greenland and Antarctica has been ruled irreversible. The degradation of glaciers worldwide will continue even if global temperatures stop rising because of changes in precipitation patterns in regions where glaciers and ice sheets exist.

Weather Events

Climatologists previously hypothesized that an increase in greenhouse gases and the subsequent increase in temperatures would lead to an increase in evaporation and precipitation. While this has not been shown to be true on a global scale, in certain regions precipitation has increased since the 2007 IPCC report. In temperate regions of the Northern Hemisphere, precipitation has increased, and some winter precipitation that would have previously fallen as snow is now falling as rain. However, in the tropics and Southern Hemisphere, precipitation amounts have remained unchanged. In the Mediterranean and West Africa, **droughts** have increased.

Extreme weather events have been increasing. The number of heat waves per year has increased since 1950, and while the frequency of tropical storms and hurricanes has not noticeably increased, there is a trend towards increased storm intensity and duration. The number of Category 4 and 5 storms has increased by about 75 percent since 1970, driven by a rise in water temperature at the surface of the ocean. Furthermore, the pathways these extreme storms travel has shifted toward the poles. Worldwide there is a general increase in precipitation intensity. In North America, heavy downpours have become more frequent and more intense in the Eastern United States, while droughts in Western states are becoming more frequent and intense.

Weather events, precipitation amounts, and surface temperatures are all interrelated. Hot days and droughts are linked together, too. Isolating one effect of global climate change from another is difficult. It is important to remember that a change in one effect will result in changes to many other Earth systems.

▪ Ocean Acidification

The oceans are a natural **carbon reservoir** and they have been able to absorb extra amounts of CO_2 being emitted. Between 1750 and 1994, the inorganic carbon content of the ocean increased by about 118 gigatons of carbon. This amount had increased in 2010 to 160 gigatons. The oceans have absorbed carbon dioxide from the atmosphere, which has lowered the oceans' pH by 0.1 pH units and has made the oceans more acidic. Scientists predict that this higher acidity will make calcification more difficult, affecting the formation of corals and marine calcifiers, including shells and skeletons by corals, crabs, marine snails, and clams. If these organisms are affected, the entire reef ecosystem (consisting of many other organisms) can also suffer.

Furthermore, the oceans will not be able to continue to absorb carbon in the amounts seen in the last 150 years. As the water temperature increases, the solubility of gases, including carbon dioxide, decreases. The northern Atlantic Ocean has been absorbing 240 megatons less carbon each year. As sea temperatures increase, the oceans' ability to absorb excess carbon from the atmosphere will be decreased.

▪ Worldwide Impacts

Scientists have data showing that greenhouse gases, particularly CO_2, are more concentrated than ever before recorded in historical data. They have been observing different indicators, including temperatures, weather events, sea levels, and ocean acidification, to determine what effect greenhouse gases are having on Earth and its inhabitants; yet much is still unknown. When it comes to predicting the impact of this concentration of carbon dioxide, scientists are unsure of exactly what may happen. Looking back through history and at current patterns, climatologists, biologists, **geologists**, **meteorologists**, and sociologists are making predictions. In the seven years between the IPCC's Fourth Assessment Report and the Fifth Assessment Report, more data, analysis, and interpretation has confirmed the effects first predicted by climatologists in the 1990s. Scientists are concerned that the indicators mentioned above, as well as other impacts, will continue to become more pronounced in the future. Because of these predictions, policy-makers worldwide have increased discussions on how best to monitor, manage, and mitigate carbon dioxide **emissions**, while maintaining quality of life and economic stability.

Mitigation Techniques

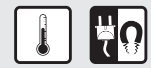
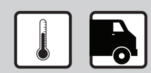
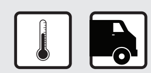
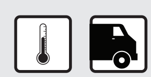
Princeton's Carbon Mitigation Initiative recommends 15 possible techniques for mitigating climate change. Climate mitigation techniques come from four sectors:

 Electricity Generation;

 Heating and Direct Fuel Use;

 Transportation; and

 Biostorage.

STRATEGY	DESCRIPTION	SECTOR
Transportation conservation	Reduce miles traveled by all vehicles	
Transportation efficiency	Double the fuel efficiency of all cars	
Efficiency in buildings	Increase insulation, furnace, and lighting efficiency	
Electricity efficiency	Increase efficiency of power generation	
Carbon Capture, Utilization, and Storage (CCUS) with coal or natural gas	CO_2 from fossil fuel power plants captured and stored underground	
CCUS with hydrogen	Hydrogen fuel from fossil fuel sources; Displaces hydrocarbon fuels	
CCUS for synfuels	Capture and store CO_2 during synfuels production from coal	
Electricity fuel switching	Replace coal-burning power plants with natural gas plants	
Nuclear electricity	Displace coal-burning power plants with nuclear plants	
Wind electricity	Wind displaces coal-based electricity	
Solar electricity	Solar PV displaces coal-based electricity	
Wind hydrogen	Produce hydrogen with wind electricity	
Biofuels	Biomass fuels from plantations replace petroleum fuels	
Forest storage	Carbon stored in new forests	
Soil storage	Farming techniques increase carbon retention or storage in soils	

Mitgating Climate Change

Carbon dioxide stays in the atmosphere for a long time. The carbon dioxide we emit and continue to emit will be present in Earth's systems for some time to come. While emissions can be slowed, it will take time before efforts that reduce emissions translate into a reduction of carbon dioxide in the system. With this knowledge, policy-makers must consider ways to **adapt** to any future impacts of climate change while planning ways to reduce emissions today. Throughout history, societies around the world have adapted to changes in their environment and have taken steps to reduce the impact of those changes on their communities.

- **Mitigation**

To mitigate climate change means to make its impact less severe. Many scientists believe that climate change can be mitigated through advances in technology and individual lifestyle modifications. Ultimately, to reduce carbon emissions to sustainable levels, we will need to increase use of, and transition to, energy sources that do not emit carbon such as uranium, solar, hydropower, and wind.

A combination of these types of actions will need to be taken on the international and governmental level, and at the individual level as well.

International Awareness

Climate change impacts every person around the globe, so climate change is an international issue. There has been a history of the international community coming together to try and make plans to combat rising levels of greenhouse gases. In 1997, the Kyoto Protocol was a first step in coming to an international agreement on greenhouse gas levels. The United States did not ratified the Kyoto Protocol because it did not have targets or timetables outlined for developing nations as well as industrialized nations.

This agreement expired in 2012; however, some participants of the Kyoto Protocol have agreed to an extension until 2020. World leaders have met periodically and continue to discuss the regulation of emissions. One of the main roadblocks is regulating GHG emissions from developing countries. These nations argue that since current climate change was primarily caused by emissions from the developed countries, those countries should bear the responsibility of lowering emissions. They see limits on GHGs as a limit to their development and their efforts to bring millions of their citizens out of poverty.

While the developed nations accept that they need to curb their emissions, they feel that developing nations will have an unfair economic advantage if they are not regulated. An international conference in Copenhagen, Denmark in 2009 ended without a strong agreement on how to regulate emissions globally. Many, but not all, countries made commitments to specific GHG targets, but there is no international system to monitor or regulate their efforts. Debate continues as to whether there should be an international system to monitor and regulate efforts to lower emissions.

Personal Awareness

Part of battling climate change is to have a better awareness and understanding of how individual actions affect climate change. People often talk about having a "carbon footprint." A carbon footprint refers to the greenhouse gas emissions caused directly and indirectly by an individual, a product, an organization, or an event. Each person has an individual carbon footprint. Each classroom, school, family, and home have specific carbon footprints. A total carbon footprint is based on several factors—how much energy is used, the way electricity is generated, water use, the types of transportation used, foods that are eaten, and products and services used. By decreasing your carbon footprint you can help decrease the production of carbon dioxide.

Greenhouse gas emissions from electricity production vary depending upon the sources of energy your utility provider uses for generation. Fossil fuels used to generate electricity produce carbon dioxide; however, hydropower, solar, and nuclear energy are considered **carbon neutral**. Using less energy, more efficient appliances, and using electricity from low or no-carbon sources are among ways to decrease your carbon footprint.

Transportation is another large part of your carbon footprint because energy is needed for almost every form of transportation. Most cars and buses use gasoline or diesel fuel and these produce GHGs as they combust. Walking or using a bicycle has no carbon impact, and carpooling and using public transportation are more efficient ways to use energy and thus contribute less GHGs than other transportation options.

Water usage is another area that influences the size of your carbon footprint. The processes of finding, purifying, treating, and transporting water involve energy and procedures that have a carbon footprint. When we are done with water, if it is transported to a sewage or water treatment plant, these steps also add to water's carbon footprint.

It is harder for people to think of individual products, like games or pencils, as adding to their carbon footprint, but our product choices impact our carbon footprint as well. Every product has a "life cycle" that includes everything that had to happen to make, deliver, and dispose of the item. Recycling products is an easy way to decrease the size of your footprint. For example, if you recycle your aluminum can you are helping save energy. Using recycled aluminum requires about 95 percent less energy than used in the original process of converting bauxite into metal. The size of your carbon footprint is adjusted based on if you reuse products, recycle them, or throw them away.

Like products, the food you eat plays a role in determining your carbon footprint. When analyzing food's impact you also have to look at the life cycle of the food you consume (an apple, for example), the amount of water and type of fertilizer used, along with the machinery and vehicles used to pack and transport the food from where it is grown to your hand—each step is part of the food's carbon footprint life cycle. After you are done eating the food, do you send it through the garbage disposal, into the trash bin, or into a compost pile?

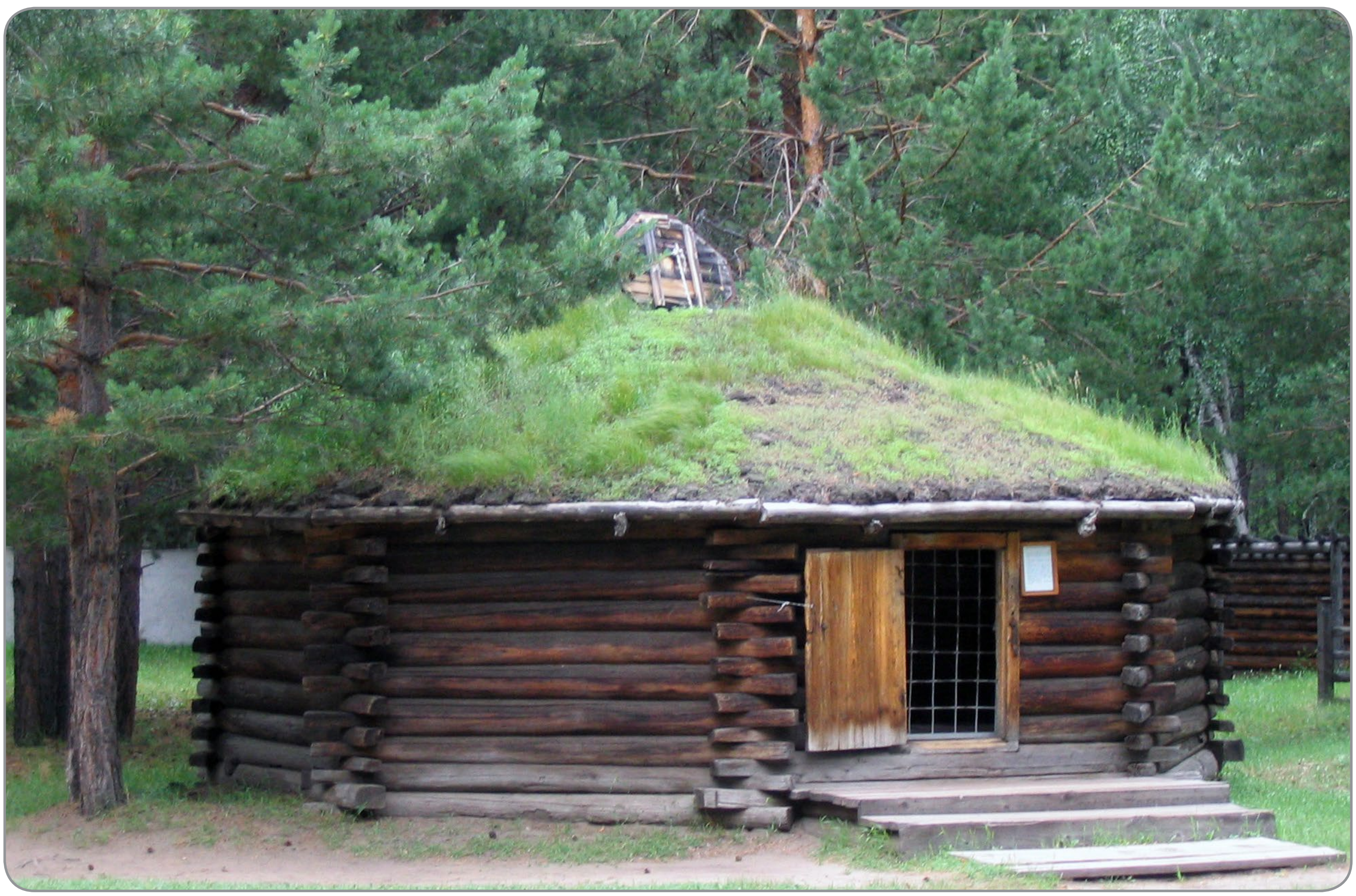
Energy Sustainability

Efficiency and conservation are key components of energy **sustainability**—the concept that every generation should meet its energy needs without compromising the needs of future generations.

Sustainability focuses on long-term energy strategies and policies that ensure adequate energy to meet today's needs as well the needs of tomorrow. Sustainability also includes investing in research and development of advanced technologies for producing conventional energy sources, promoting the use of alternative energy sources, and encouraging sound environmental policies and practices.

Looking to the Future

Our environment provides us with all of the essential resources we need. It provides us with sources of food, water, and oxygen, as well as reservoirs that can store and process the waste or byproducts created by our activities. How do we balance our need for energy with the importance of efficiency and conservation? While this issue is very complex, creative solutions by government and industry can lead to a thriving economy and stable climate. It is the choice of individuals that makes the most difference. Using energy wisely and conserving our resources is a good idea.



A sustainable home.

Climate Change KWL Chart

What I Think I Know	What I Want to Know	What I Learned

Properties of CO_2

What are the properties of CO_2 as a solid and a gas? Record your observations below.

Greenhouse in a Beaker

Question

What affect does adding carbon dioxide to the air have on the air's temperature during the day and during the night?

Hypothesis

In your science notebook, record your hypothesis in an "If...then...because..." format.

Materials

- 2 600 mL Beakers
- 1 250 mL Flask
- 1 Rubber stopper with hole
- 1 Vinyl tubing, 3/16" diameter, 60 cm long
- 1 Clip light
- 1 1000-1100 lumen Bulb (equivalent to 75-watt incandescent)
- 1 Ruler
- 2 Probe thermometers
- Small piece of masking tape
- 4 Alka-Seltzer® tablets
- Safety glasses
- 240 mL Water (room temperature)

✔ Procedure

Part 1—Day

1. Set up the light source 15 cm in front of the two beakers. The beakers should be receiving equal light.
2. Insert the tubing through the hole in the 250 mL flask, making sure to keep the tubing from reaching the bottom of the flask. Place the other end of the tubing near the bottom of one of the beakers. Secure the tubing inside this beaker with a small piece of masking tape.
3. Add 120 mL of water to the flask. Be sure the tubing is not in the water.
4. Turn on the clip light. Wait for the temperature in each beaker to stabilize. The temperatures in the beakers should be similar, but they do not have to be exactly the same.
5. Record the stable temperature of each beaker in the data table.
6. Break two Alka-Seltzer® tablets in half and drop the pieces into the flask. Secure the rubber stopper into the flask and make sure the tubing still leads from the flask to the beaker.
7. Record the temperature of each beaker every 30 seconds for three minutes.

Part 2—Night

1. After you have data to model temperatures during the day, empty out your beakers and flask. Refill the flask with 120 mL water. Resecure the tubing inside one of the beakers.
2. Turn on the clip light. Wait for the temperature to stabilize. The temperatures in the beakers should be similar, but they do not have to be exactly the same.
3. Record the stable temperature of each beaker in the data table.
4. Break two more Alka-Seltzer® tablets in half and drop the pieces into the flask. Secure the rubber stopper as done before.
5. Turn off the light.
6. Record the temperature of each beaker every 30 seconds for three minutes.

Data

Record your data in these tables or copy the tables into your science notebook.

Simulated Day Data

	BEAKER 1 (WITHOUT CO_2)	BEAKER 2 (WITH CO_2)
Beginning Temperature		
30 seconds		
1 minute		
1 minute, 30 seconds		
2 minutes		
2 minutes, 30 seconds		
3 minutes		

Simulated Night Data

	BEAKER 1 (WITHOUT CO_2)	BEAKER 2 (WITH CO_2)
Beginning Temperature		
30 seconds		
1 minute		
1 minute, 30 seconds		
2 minutes		
2 minutes, 30 seconds		
3 minutes		

Create a graph displaying both the day and night temperatures for both beakers.

Conclusions

1. Do you accept or reject your hypothesis? What were the results of your investigation? Use data to explain what happened.
2. Why do you think this happened?
3. How does this demonstration relate to climate change?

Carbon Reservoir Comparison

Atmosphere	Biosphere

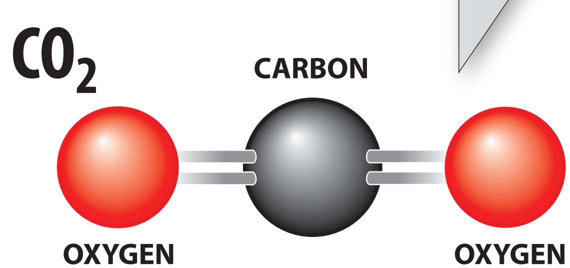
Hydrosphere	Lithosphere

Atmosphere — CO_2 Gas

You are a CO_2 molecule in the atmosphere.

You came from

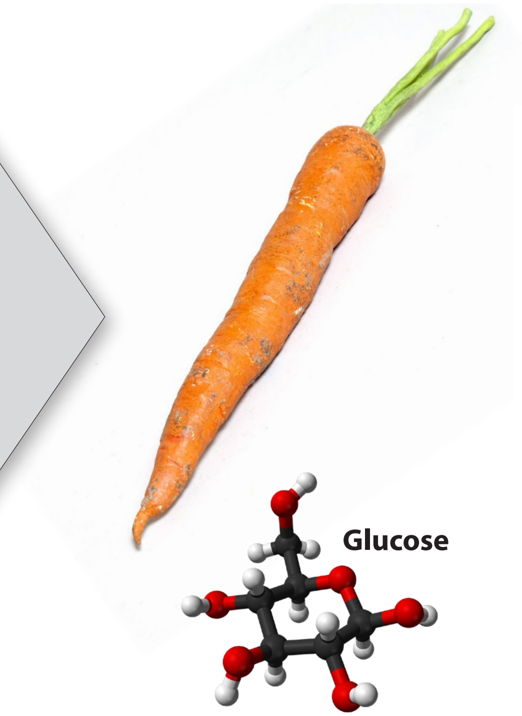
- the hydrosphere by **degassing**, or
- land animals or soil through **respiration**, or
- from the lithosphere through the **combustion** of fossil fuels.



Biosphere — Land Plant

You are now part of a glucose molecule in a carrot.

You came as a **carbon dioxide molecule** from the atmosphere by the **photosynthesis** process.



Through photosynthesis, a plant combined carbon, water, and solar energy to create a molecule of glucose.

$$6CO_2 + 6H_2O + \text{Energy} \longrightarrow C_6H_{12}O_6 + 6O_2$$

Biosphere — Soil

You are now part of an organic molecule in the soil.

You came as part of a **protein molecule** in a plant or animal that died and decomposed.

You became part of an organic molecule in the soil through the process of respiration in soil microbes.

Biosphere — Land Animal

You are now part of a protein molecule in a rabbit.

You came as a **glucose molecule** from a carrot in the biosphere through the **consumption** process.

Glucose: $C_6H_{12}O_6$

The rabbit ate a carrot and through digestion and respiration broke down the glucose molecule, which released energy for her to use to hop around. The glucose molecule broke down into molecules of carbon dioxide and water and the carbon eventually became part of a protein molecule.

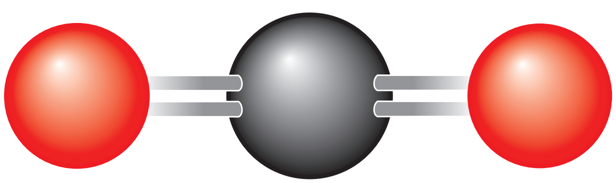
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6\,H_2O + \text{Energy}$$

Hydrosphere — Ocean

You are part of a dissolved CO_2 molecule in the ocean.

You came as part of a **carbon dioxide molecule** from the atmosphere by the **dissolution** process or from a marine animal through **respiration**.

CO_2



Hydrosphere — Marine Plant

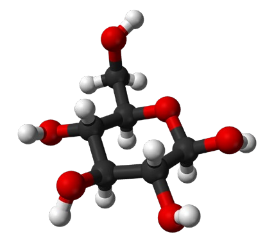
You are now part of a glucose molecule in seaweed.

You came as part of a **carbon dioxide molecule** from the hydrosphere-ocean through the **photosynthesis** process.

Through photosynthesis, a plant used water and energy from the sun to create a molecule of glucose.

$$6CO_2 + 6H_2O + \text{Energy} \longrightarrow C_6H_{12}O_6 + 6O_2$$

Glucose



Hydrosphere — Marine Animal

You are now part of a protein molecule in a sea turtle.

You came as part of a **glucose molecule** from seaweed in the hydrosphere through the **consumption** process.

The turtle ate seaweed and through digestion and respiration, broke down the glucose molecule, which released energy for her to use to swim around. The glucose molecule broke down into molecules of carbon dioxide and water and the carbon eventually became part of a protein molecule.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Lithosphere — Fossil Fuel

You are now part of a hydrocarbon molecule in fossil fuels.

You are part of a **hydrocarbon molecule** in the lithosphere. You are a part of all fossil fuels. Fossil fuels took millions of years to form.

Fossil fuels are made up of hydrocarbon molecules, which are made up of carbon, hydrogen, and oxygen atoms. Fossil fuels include coal, petroleum, and natural gas. Until people discovered how to burn fossil fuels to create energy and for other uses, the hydrocarbons stayed underground for millions of years.

CARBON CYCLE SIMULATION

The Atmosphere: CO_2 Gas Pre-Industrial Round

You are now part of a carbon dioxide molecule in the atmosphere.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE LAND PLANT RESERVOIR	GO TO THE OCEAN RESERVOIR	STAY IN THE ATMOSPHERE RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start				
1	Two Highest Cards	Next Three Highest Cards	All Others	
2	Two Highest Cards	Next Three Highest Cards	All Others	
3	Two Highest Cards	Next Three Highest Cards	All Others	
4	Two Highest Cards	Next Three Highest Cards	All Others	
5	Two Highest Cards	Next Three Highest Cards	All Others	
6	Two Highest Cards	Next Three Highest Cards	All Others	
7	Two Highest Cards	Next Three Highest Cards	All Others	
8	Two Highest Cards	Next Three Highest Cards	All Others	
9	Two Highest Cards	Next Three Highest Cards	All Others	
10	Two Highest Cards	Next Three Highest Cards	All Others	

CARBON CYCLE SIMULATION

The Atmosphere: CO_2 Gas Present-Day Round

You are now part of a carbon dioxide molecule in the atmosphere.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE LAND PLANT RESERVOIR	GO TO THE OCEAN RESERVOIR	STAY IN THE ATMOSPHERE RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start				
1	Two Highest Cards	Next Three Highest Cards	All Others	
2	Two Highest Cards	Next Three Highest Cards	All Others	
3	Two Highest Cards	Next Four Highest Cards	All Others	
4	Two Highest Cards	Next Three Highest Cards	All Others	
5	Two Highest Cards	Next Four Highest Cards	All Others	
6	Two Highest Cards	Next Three Highest Cards	All Others	
7	Two Highest Cards	Next Four Highest Cards	All Others	
8	Two Highest Cards	Next Four Highest Cards	All Others	
9	Two Highest Cards	Next Four Highest Cards	All Others	
10	Two Highest Cards	Next Three Highest Cards	All Others	

CARBON CYCLE SIMULATION

The Biosphere: Land Plant All Rounds

You are now part of a glucose molecule in a carrot.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE LAND ANIMAL RESERVOIR	GO TO THE SOIL RESERVOIR	STAY IN THE LAND PLANT RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start				
1	High Card	Low Card	All Others	
2	Two Highest Cards		All Others	
3	High Card	Low Card	All Others	
4	Two Highest Cards		All Others	
5	High Card	Low Card	All Others	
6	Two Highest Cards		All Others	
7	High Card	Low Card	All Others	
8	Two Highest Cards		All Others	
9	High Card	Low Card	All Others	
10	Two Highest Cards		All Others	

CARBON CYCLE SIMULATION

The Biosphere: Land Animal All Rounds

You are now part of a protein molecule in a rabbit.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE ATMOSPHERE	GO TO THE SOIL RESERVOIR	STAY IN THE LAND ANIMAL RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start				
1	High Card		All Others	
2	High Card	Low Card	All Others	
3	High Card		All Others	
4	High Card	Low Card	All Others	
5	High Card		All Others	
6	High Card	Low Card	All Others	
7	High Card		All Others	
8	High Card	Low Card	All Others	
9	High Card		All Others	
10	High Card	Low Card	All Others	

CARBON CYCLE SIMULATION

The Biosphere: Soil All Rounds

You are now part of an organic molecule in the soil.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE ATMOSPHERE RESERVOIR	**STAY IN THE SOIL RESERVOIR**	**NUMBER OF CARBONS IN THIS RESERVOIR**
Start			
1	High Card	All Others	
2	High Card	All Others	
3	High Card	All Others	
4	High Card	All Others	
5	High Card	All Others	
6	High Card	All Others	
7	High Card	All Others	
8	High Card	All Others	
9	High Card	All Others	
10	High Card	All Others	

CARBON CYCLE SIMULATION

The Hydrosphere: Ocean All Rounds

You are now part of a dissolved carbon dioxide molecule in the ocean.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE ATMOSPHERE RESERVOIR	GO TO THE MARINE PLANT RESERVOIR	STAY IN THE OCEAN RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start				
1	Three Highest Cards	Low Card	All Others	
2	Three Highest Cards	Low Card	All Others	
3	Three Highest Cards	Low Card	All Others	
4	Three Highest Cards	Low Card	All Others	
5	Three Highest Cards	Low Card	All Others	
6	Three Highest Cards	Low Card	All Others	
7	Three Highest Cards	Low Card	All Others	
8	Three Highest Cards	Low Card	All Others	
9	Three Highest Cards	Low Card	All Others	
10	Three Highest Cards	Low Card	All Others	

CARBON CYCLE SIMULATION

The Hydrosphere: Marine Plant All Rounds

You are now part of a glucose molecule in seaweed.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the “I arrived here by the process of …" and “What I am now” columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the “Next I am going to the…” column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE MARINE ANIMAL RESERVOIR	STAY IN THE MARINE PLANT RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start			
1	High Card	All Others	
2	High Card	All Others	
3	High Card	All Others	
4	High Card	All Others	
5	High Card	All Others	
6	High Card	All Others	
7	High Card	All Others	
8	High Card	All Others	
9	High Card	All Others	
10	High Card	All Others	

The Hydrosphere: Marine Animal All Rounds

You are now part of a protein molecule in a sea turtle.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE OCEAN RESERVOIR	STAY IN THE MARINE ANIMAL RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start			
1	High Card	All Others	
2	High Card	All Others	
3	High Card	All Others	
4	High Card	All Others	
5	High Card	All Others	
6	High Card	All Others	
7	High Card	All Others	
8	High Card	All Others	
9	High Card	All Others	
10	High Card	All Others	

CARBON CYCLE SIMULATION

The Lithosphere: Fossil Fuel Present-Day Round

You are now part of a hydrocarbon molecule in fossil fuels.

1. When you arrive, use the *Carbon Tracking Sheet* and the poster to fill in the "I arrived here by the process of …" and "What I am now" columns of your worksheet.
2. Record the total number of carbons in this reservoir in the space provided below.
3. When directed, each person draws a card. Use the chart below to figure out where each person goes next. Then each person fills in the "Next I am going to the…" column on their worksheet.
4. Return cards to a pile and shuffle.
5. WAIT UNTIL YOU ARE DIRECTED TO MOVE TO YOUR NEW RESERVOIR.

	GO TO THE ATMOSPHERE RESERVOIR	STAY IN THE LITHOSPHERE RESERVOIR	NUMBER OF CARBONS IN THIS RESERVOIR
Start			
1	High Card	All Others	
2	High Card	All Others	
3	High Card	All Others	
4	High Card	All Others	
5	High Card	All Others	
6	High Card	All Others	
7	High Card	All Others	
8	High Card	All Others	
9	High Card	All Others	
10	High Card	All Others	

Carbon Tracking Sheet

Name: ______________________________ Round: ____________________

Use the posters and playing cards to help complete the table.

TURN	I ARRIVED HERE BY THE PROCESS OF...	WHAT I AM NOW	NEXT I AM GOING TO THE...
START		I am part of a(n) ____________________molecule in ____________________	
1		I am now part of a(n) ____________________molecule in ____________________	
2		I am now part of a(n) ____________________molecule in ____________________	
3		I am now part of a(n) ____________________molecule in ____________________	
4		I am now part of a(n) ____________________molecule in ____________________	
5		I am now part of a(n) ____________________molecule in ____________________	
6		I am now part of a(n) ____________________molecule in ____________________	
7		I am now part of a(n) ____________________molecule in ____________________	
8		I am now part of a(n) ____________________molecule in ____________________	
9		I am now part of a(n) ____________________molecule in ____________________	
10		I am now part of a(n) ____________________molecule in ____________________	

Road Trip

The Challenge

Energy is required to transport you from place to place. In the United States, the transportation sector consumes 28 percent of total energy supply and is responsible for about one-third of the greenhouse gases emitted each year.

Plan a four day road trip vacation. Where would you go? What stops would you make along the way?

1. Select a vehicle make and model for your trip, then find its fuel economy ratings at www.fueleconomy.gov. Fill in the information below.

   Vehicle Make and Model: ____

   Fuel Type: ________________________ Fuel Economy (MPG): ______________________

2. In the chart's left hand column, plan out each segment of your trip. Use the data and formulas provided below to calculate how many gallons of fuel will be required, and the amount of CO_2 emissions.

The EPA uses the following CO_2 emission values. Circle the value you will use in your calculations.
Gasoline CO_2 Emissions = 19.6 pounds/gallon
Diesel CO_2 Emissions = 22.4 pounds/gallon
Miles Driven/MPG = Total Gallons Consumed
Total Gallons Consumed x CO_2 Emissions pounds/gallon = Total CO_2 Emissions

TO	FROM	MILES	GALLONS CONSUMED	TOTAL CO_2 EMISSIONS

Answer the Following Questions

1. Why did you choose the vehicle you chose?
2. What is the total amount of CO_2 emissions associated with your trip?
3. What is the price of fuel in your area? How much will fuel for the entire trip cost?
4. Are there ways you can reduce your fuel consumption on this trip?
5. Are there some portions of your trip where you can use public transportation? Why or why not?
6. How would using public transportation compare to driving your own personal vehicle?
7. A 2014 Volkswagen Jetta using diesel fuel is rated to get mileage of up to 42 mpg. A 2014 Volkswagen Jetta using regular gasoline gets 26-34 mpg. Which car would be better to take on your road trip? Use data to explain your reasoning.
8. Can you find a less expensive, less carbon intensive vehicle than your first vehicle choice? Find at least two alternatives and explain how they compare to your original vehicle.

Resources: For more information on alternative fuel vehicles, visit the U.S. Department of Energy's Alternative Fuels and Advanced Vehicles Data Center at www.afdc.energy.gov/.

Carbon Footprint

Given

- The average gallon of gas contains about 5 lbs. of carbon.
- One five-pound bag of charcoal briquettes contains approximately 100 briquettes.
- 5 lbs. of carbon/100 briquettes = 0.05 lbs. carbon per briquette

Sample Problems

1. If you drive or ride in a vehicle that averages 25 mpg, how many briquettes per mile would you be emitting?

2. If each briquette contains 0.05 lbs. of carbon, how many lbs. of carbon are emitted each mile?

Questions

1. How many miles per gallon does your car (or your family car) average?

2. How many briquettes per mile would be emitted while traveling in your vehicle?

3. If each briquette contains 0.05 lbs. of carbon, how many lbs. of carbon are you emitting per mile?

4a. How many miles do you travel to school?

4b. Calculate how much carbon dioxide you are emitting as you travel to school.

5a. How many miles do you travel on the average day? Think about everywhere you go.

5b. Calculate how much carbon dioxide you are emitting as you travel on an average day.

Conclusions

1. Do you think people would change their behavior if carbon dioxide was emitted in a visible way, such as charcoal briquettes, rather than as a gas? Why or why not?
2. What are challenges in decreasing carbon dioxide emitted from our vehicles?
3. What might be some options for reducing the amount of carbon dioxide emitted from the transportation sector?

Climate Web

Energy Efficiency and Conservation	In using energy wisely we decrease CO_2 emissions from power plants and vehicles.
Atmosphere	Our atmosphere keeps us alive and warm. Gases in the atmosphere control amounts of ultraviolet radiation reaching the planet and determine the Earth's temperature, keeping us warm. Without gases in the atmosphere, it would be so cold, almost nothing could survive. However, as CO_2 levels in the atmosphere rise, greater differences in air temperature create more unstable weather patterns.
Transportation	Transportation is very important to us. We use it to travel and ship products. We must have transportation to get people and products to places throughout the world, but different modes of transportation need fuel to work and emit CO_2 and other emissions into our atmosphere.
Trees	Humans could not survive without trees and other plants. Trees take in CO_2 and through the process of photosynthesis produce oxygen for us to breathe, as well as providing shade, wood products, and beauty. Trees are a renewable resource.

Climate Web

Animals	Animals exhale CO_2 through natural respiration. We must have animals for food and equilibrium in ecosystems. Animals are used extensively for food and other products.
People	We need and use a lot of energy daily. Our homes, communities, and modes of transportation all use energy in various ways. We use more energy today than ever before. Much of our energy use comes from fossil fuels. Energy production from fossil fuels emits CO_2 and other emissions into the atmosphere.
Solar Energy	Solar energy is radiant energy emitted by the sun. Through the use of solar panels, we can harness this energy to power our homes and heat water. Solar energy is a renewable resource that does not produce CO_2 emissions.
Carbon Capture, Utilization, and Storage	New technology allows us to store CO_2 emissions from power plants underground to be used later. This may be an effective way to limit the amount of CO_2 we put into the atmosphere. We do not know yet how effective this strategy is at storing CO_2 in the long term.

Climate Web

Nuclear Plant	Uranium ore is mined then processed at nuclear power plants to produce electrical energy we need for homes and industry. Nuclear energy is a nonrenewable resource that produces no CO_2 emissons. Using nuclear power is controversial because of potential risk of radiation, if it is not contained.
Mining	Through mining, we extract ore and minerals from the Earth. We extract coal and uranium in this way to use for electricity production. Machinery used in mining emits CO_2 and other emissions. By removing vegetation, the ability of the land to remove CO_2 from the atmosphere is decreased.
Soil	Soil is the top layer of the Earth's surface, consisting of rock and mineral particles mixed with organic matter. We need healthy soil for growing food. Soil stores carbon, keeping it from the atmosphere. Developing and tilling and other activities that disturb the soil release this stored carbon into the atmosphere.
Crops	The crops we grow are essential to our survival. Growing crops also produces CO_2 emissions through the use of farm equipment, pesticides, fertilizers, and tilling the soil. Crops also remove CO_2 from the atmosphere as they grow.

Climate Web

Petroleum	Petroleum is a nonrenewable fossil fuel formed hundreds of millions of years ago. We use more petroleum than any other energy source. Some product benefits include transportation fuels, fertilizers, plastics, and medicines. Petroleum must be burned to release the energy, which emits CO_2.
Refineries	Refineries are industrial plants that refine petroleum into useable products. We refine crude oil for fuels such as gasoline, jet fuel, and fuel oils needed for transportation. Production, distribution, and consumption release CO_2.
Coal	Coal is a nonrenewable fossil fuel created from the remains of plants that lived and died millions to hundreds of millions of years ago. We extract coal from the Earth to use as fuel for electricity, industry, and heating, as well as in making iron and steel. We burn coal to release energy. Burning coal releases CO_2.
Coal Plants	Coal plants clean, process, and burn coal to generate electricity. Burning coal releases CO_2 into the atmosphere.

Climate Web

Oceans	Oceans are carbon reservoirs, which means they have the ability to absorb CO_2. This process of absorption helps keep our planet cooler. However, adding CO_2 to the ocean makes it more acidic, which impacts ocean ecosystems.
Natural Earth Events	Geological evidence tells us that the Earth's climate has changed a lot over time. Natural Earth events are factors that can contribute to climate change. Earth's position relative to the sun, volcanic eruptions, forest fires, and ocean currents are factors that can affect climate.
Economy	A growing economy demands more energy and electricity, and can increase CO_2 emissions if fossil fuels are used. Energy efficiency and conservation reduces CO_2 emissions and energy bills for families, schools, and companies.

Climate Systems

★ Concepts

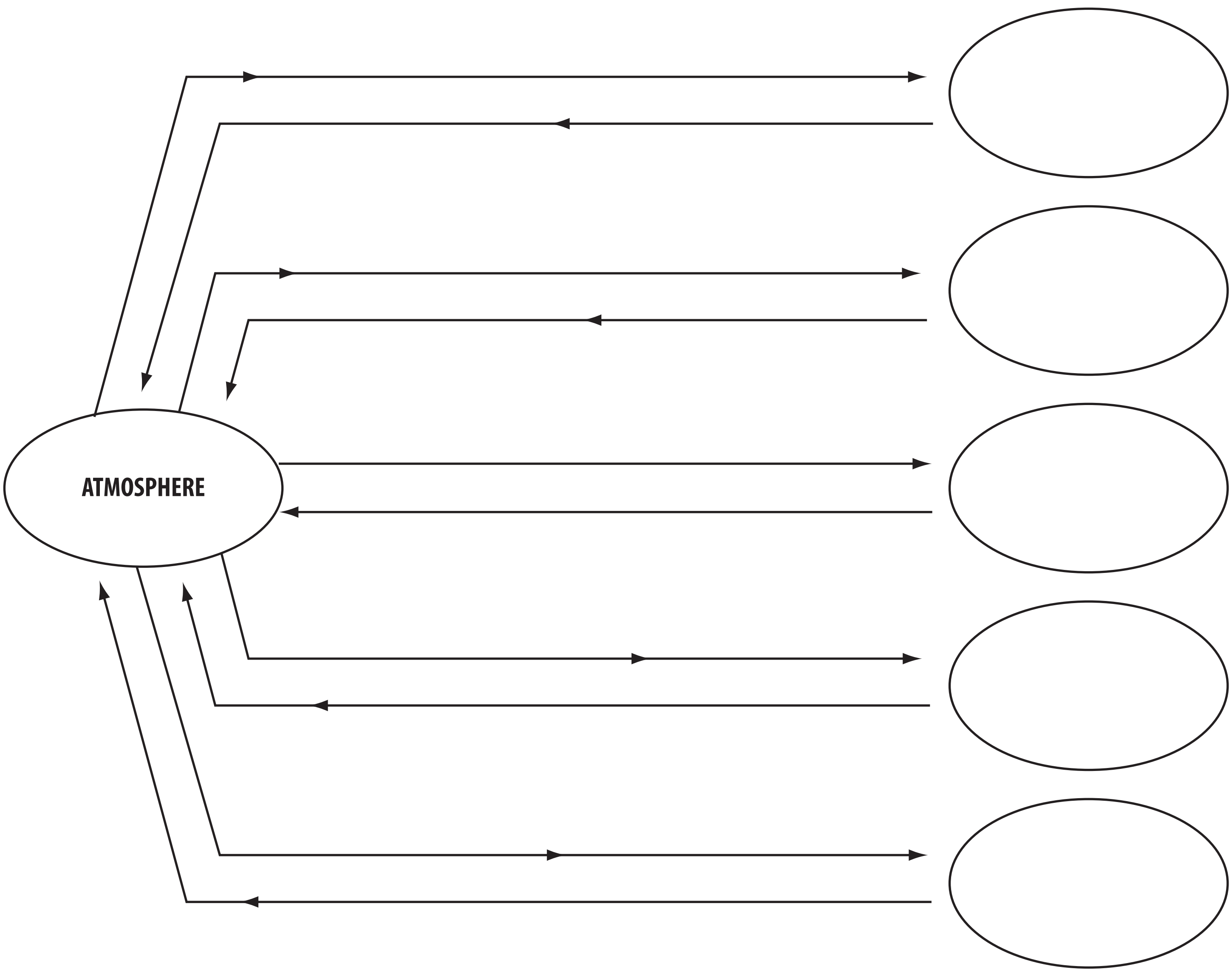
Each of the components listed below affects the atmosphere, which in turn affects the other components of the climate system.

Some Components of the Climate System:

Animals
Atmosphere
Coal
Coal Plants
Crops
Economy
Energy Efficiency/Conservation
Carbon Capture, Utilization, and Storage
Mining
Natural Earth Events
Nuclear Plant
Oceans
People
Petroleum
Refineries
Soil
Solar Energy
Transportation
Trees

✔ Procedure

Atmosphere has been filled in for you. Select five (5) other components from the list above and write them in the bubbles on the right. On the lines between the bubbles, write how the atmosphere affects the climate system component, and how the component affects the atmosphere, using the arrows as a guide.



Electric Nameplates

Some appliances use more energy than others to accomplish the same task. Appliances that are very energy efficient are approved by the government's ENERGY STAR® program and have the ENERGY STAR® label on them. This means they have met high standards set by the government for energy efficiency.

Every machine that runs on electricity has an electric nameplate on it. The nameplate is usually a silver sticker that looks like the picture below. The nameplate has information about the amount of electricity the machine uses. Sometimes, the current is listed. The current is measured in amperes (A). Sometimes, the voltage the machine needs is listed. The voltage is listed in volts (V). Sometimes, the wattage is listed. The wattage is measured in watts (W). If the wattage isn't listed, then the current and voltage are both listed.

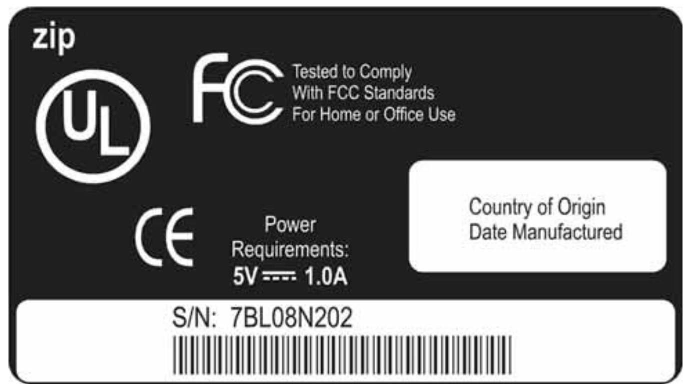
If the wattage is not listed, you can calculate the wattage using the following formula:

wattage = current x voltage

W = A x V

W = 1.0A x 5V

W = 5W



Often, the letters UL are on the nameplate. UL stands for Underwriters Laboratories, Inc., which conducts tests on thousands of machines and appliances. The UL mark means that samples of the machines and appliances have been tested to make sure they are safe.

You can find out how much it costs to operate any appliance or machine if you know the wattage. Let's take a look at some of the machines in your school. The nameplate is usually located on the bottom or back. See if you can find the nameplates on the computers, printers, monitors, televisions, and other machines in your classroom. Put the information in the chart below and figure out the wattage for each one.

MACHINE OR APPLIANCE	CURRENT	VOLTAGE	WATTAGE	UL TESTED
Copier	*11A*	*115V*	*1,265W*	*yes*

Cost of Using Machines

Calculate how much it costs to operate the machines in your classroom that you looked at before. You need to know the wattage, the cost of electricity, and the number of hours a week each machine is used.

You can estimate the number of hours the machine is used each week, then multiply by 40 to get the yearly use. We are using 40 weeks for schools, because school buildings aren't used every week of the year. Using the copier as an example, if it is used for ten hours each week, we can find the yearly use like this:

Yearly use = 10 hours/week x 40 weeks/year = 400 hours/year

Remember that electricity is measured in **kilowatt-hours**. You will need to change the watts to kilowatts. One kilowatt is equal to 1,000 watts. To get kilowatts, you must divide the watts by 1,000. Using the copier as an example, divide like this:

kW = W/1,000

kW = 1,265/1,000 = 1.265

The average cost of electricity for schools in the U.S. is about eleven cents per kilowatt-hour. You can use this rate or find out the actual rate from your school's electric bill. Using the average cost of electricity, we can figure out how much it costs to run the copier for a year by using this formula:

Yearly cost = Hours used x Kilowatts x Cost of electricity (kWh)

Yearly cost = 400 hours/year x 1.265 kW x $0.11/kWh

Yearly cost = 400 x 1.265 x 0.11 = $55.66

MACHINE OR APPLIANCE	HOURS PER WEEK	HOURS PER YEAR	WATTS (W)	KILOWATTS (kW)	RATE ($/kWh)	ANNUAL COST
Copier	*10*	*400 hours*	*1,265 W*	*1.265 kW*	*$0.11*	*$55.66*

Environmental Impact

When we breathe, we produce carbon dioxide. When we burn fuels, we produce carbon dioxide too. Carbon dioxide (CO_2) is a greenhouse gas. Greenhouse gases hold heat in the atmosphere. They keep our planet warm enough for us to live, but since the Industrial Revolution, we have been producing more carbon dioxide than ever before. Since 1850, the level of CO_2 in our atmosphere has increased more than 45 percent.

Research shows that greenhouse gases are trapping more heat in the atmosphere. Scientists believe this is causing the average temperature of the Earth's atmosphere to rise. They call this global climate change or global warming. Global warming refers to an average increase in the temperature of the atmosphere, which in turn causes changes in climate. A warmer atmosphere may lead to changes in rainfall patterns, a rise in sea level, and a wide range of impacts on plants, wildlife, and humans. When scientists talk about the issue of climate change, their concern is about global warming caused by human activities.

Driving cars and trucks produces carbon dioxide because fuel is burned. Heating homes by burning natural gas, wood, heating oil, or propane produces carbon dioxide too.

Making electricity can also produce carbon dioxide. Some energy sources—such as hydropower, solar, wind, geothermal, and nuclear—do not produce carbon dioxide, because no fuel is burned. About 33.08 percent of our electricity, however, comes from burning coal. Another 35.50 percent comes from burning natural gas, petroleum, and biomass.

The general rule is that, on average, every kilowatt-hour of electricity produces 1.5 pounds of carbon dioxide. Let's use this rule to figure out how much carbon dioxide is produced by the machines in your classroom. You can put the figures from the earlier worksheets in the boxes below. Here are the figures for the copier:

CO_2 a year = wattage x hours of use x rate of CO_2/kWh

CO_2 a year = 1.265 kW x 400 hr/yr x 1.5 lb/kWh = 759 lbs

MACHINE OR APPLIANCE	KILOWATTS (kW)	RATE OF CO_2/kWh (LBS)	HOURS PER YEAR	CO_2/YEAR (LBS)
Copier	*1.265 kW*	*1.5*	*400 hours*	*759*

Wedge Challenge

Teacher Guide

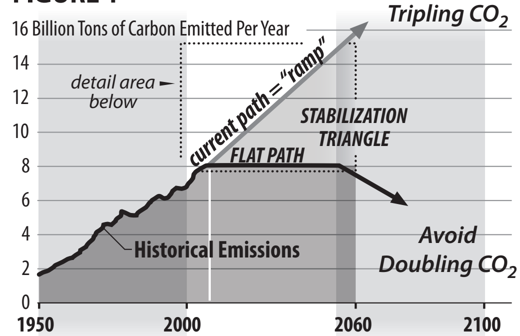
Overview

Students become decision makers and work in teams to determine the technologies and practices that will be most effective at reducing carbon emissions and stabilizing our climate. The core purpose of this activity is to convey the scale of effort needed to address the carbon and climate situation and the necessity of developing a portfolio of carbon-cutting options. By the end of the exercise, students should understand the magnitude of human-sourced carbon emissions and feel comfortable comparing the effectiveness, advantages, and drawbacks of a variety of carbon-cutting strategies. The students should appreciate that there is no easy or "right" solution to the carbon and climate problem. A version is also included where students choose actions to provide personal wedges.

Background

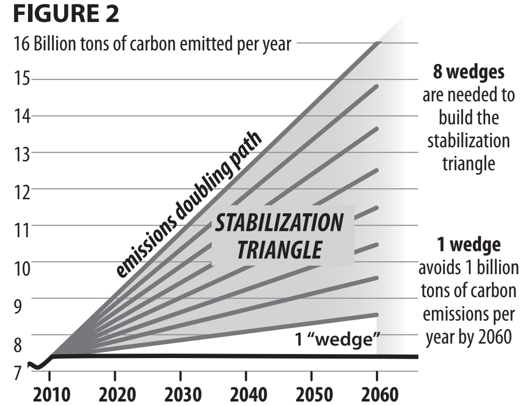
The "stabilization wedges" concept is a simple tool for conveying the emissions cuts that can be made to avoid dramatic climate change. We consider two futures—allowing emissions to double versus keeping emissions at current levels for the next 50 years. The emissions-doubling path (Figure 1, grey line) falls in the middle of the field of most estimates of future carbon emissions. The ramp approximately extends the climb for the past 50 years, during which the world's economy grew much faster than its carbon emissions. Emissions could be higher or lower in 50 years, but this path is a reasonable reference scenario.

FIGURE 1



In contrast, we can prevent a doubling of CO_2 if we can keep emissions flat for the next 50 years, then work to reduce emissions in the second half of the century (Figure 1, black line). This path is predicted to keep atmospheric carbon under 1200 billion tons (which corresponds to about 570 parts per million (ppm)), allowing us to skirt the worst predicted consequences of climate change.

FIGURE 2



A master of the Stabilization Wedges is available on page 87.

Keeping emissions flat will require cutting projected carbon output by about 8 billion tons per year by 2060, keeping a total of about 200 billion tons of carbon from entering the atmosphere. This carbon savings is what we call the "stabilization triangle" (Figure 2). The conventional wisdom has been that only revolutionary new technologies like nuclear fusion could enable such large emissions cuts. There is no reason, however, why one tool should have to solve the whole problem.

CMI set out to quantify the impact that could be made by a portfolio of existing technologies deployed on a massive scale. To make the problem more tractable, the researchers divided the stabilization triangle into eight "wedges." A wedge represents a carbon-cutting strategy that has the potential to grow from its present level of deployment, to avoiding an additional 1 billion tons of carbon emissions per year by 2060, or one-eighth of the stabilization triangle. The wedges can represent ways of either making energy with no or reduced carbon emissions (like nuclear or wind-produced electricity), or storing carbon dioxide to prevent it from building up as rapidly in the atmosphere (either through underground storage or biostorage).

This activity is based on the Wedge Game, developed by the Carbon Mitigation Initiative (CMI) at Princeton University's Princeton Environmental Institute (PEI). CMI is a joint project of Princeton University, BP, and Ford Motor Company to find solutions to the greenhouse gas problem. To emphasize the need for early action, Co-Directors Robert Socolow and Stephen Pacala created the concept of stabilization wedges. Each wedge represents 25 billion ton "wedges" that need to be cut out of predicted future carbon emissions in the next 50 years, to avoid a doubling of atmospheric carbon dioxide over pre-industrial levels.

***NOTE: Activity borrowed as-is from CMI. CMI has not updated data in their game as recently as NEED. Not all facts and figures will match NEED text.**

Why are emissions predicted to double? While there are many reasons, three main factors are:

- Increased population
- Increased energy use by developing nations as they industrialize
- Increased energy use in developed nations

Because of these pressures, it will take a tremendous effort to reduce carbon emissions to the levels necessary to reverse the atmospheric warming trend.

Keeping emissions flat will require the world's societies to "fill in" the eight wedges of the stabilization triangle. In CMI's analysis, at least 15 strategies are available now that, with scaling up, could each take care of at least one wedge of emissions reduction. No one strategy can take care of the whole triangle. New strategies will be needed to address both fuel and electricity needs, and some wedge strategies compete with others to replace emissions from the same source—but there is already a more than adequate portfolio of tools available to control carbon emissions for the next 50 years.

NOTE: Even though all of the wedges appear to start from zero, understand that "zero" includes all of the efforts that have been implemented to date related to that wedge strategy. For instance, even though a wedge of nuclear electricity appears to start from zero, there is already significant deployment of this strategy worldwide.

NOTE: While much of the climate and energy curriculum references carbon in the atmosphere in units of carbon dioxide or methane, the figures used in this activity (mass, concentration, etc.) refer to carbon, alone. To convert from units of carbon to units of carbon dioxide, multiply the mass of the carbon by 3.67. To convert from CO_2 to carbon, multiply by 0.2727.

★ Concepts

We can stabilize climate with technology that exists today. Choosing the technologies to support and deploy involves making challenging choices.

✪ Objective

Students will learn about the technologies currently available that can substantially cut carbon emissions, develop critical reasoning skills as they create their own portfolio of strategies to cut emissions, and verbally communicate the rationale for their selections. Working in teams, students will develop the skills to negotiate a solution that is both physically plausible and politically acceptable, and defend their solution to a larger group.

Time

Four class periods

Materials and Preparation

- Tape
- Scissors
- Make enough copies of the activity materials ahead of time.
- Photocopy the wedge pieces (page 90) on colored paper as follows:
    - Transportation—Blue
    - Heat—Yellow
    - Electricity—Red/Pink
    - Biostorage—Green
- Cut each sheet in half, providing one full triangle of wedges for each sector to each group.
- Divide the class into teams of 3-5 students each.
- Each group should have the following materials:
    - *Wedge Challenge Student Guide* (pages 71-75)
    - *Wedge Table* (page 80)
    - *Wedge Gameboard* (page 81)
    - *Wedge Worksheet* (page 82)
    - *Intensification Wedge* (page 83)
    - *Wedge Intensification Worksheet* (page 84)
    - *Personal Wedge Guidelines* (pages 85-86)
- Each student should have a copy of each *Wedge Ratings* sheet (pages 76-79).

✔ Procedure

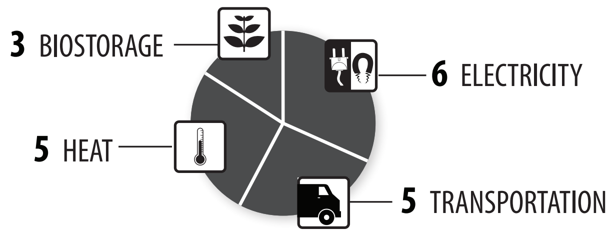
Day One (20-45 minutes)

1. Introduce the activity by saying, "The Earth's atmosphere currently contains about 830 billion tons of carbon as CO_2, and combustion of fossil fuels currently adds about 8 billion tons of carbon every year. At this rate, we are on track to double the amount of carbon in the atmosphere, as compared to pre-industrial levels, before the end of the century. Can we change this course? While it is likely to be challenging, fortunately, we can and we can also do it with technology that is available or in development today. In the Wedge Challenge, you will be working on a team to decide what you feel are the eight most promising strategies out of 15 possible choices."
2. Form teams of 3 to 5 students. It is particularly helpful to have each student be an appointed "expert" in a few of the technologies to promote good discussions. You may want to identify a recorder and reporter in each group.
3. Explain the rules, referring students to the *Wedge Challenge Student Guide*.
4. Explain to the students that in the first step, they will be working individually to complete rating sheets about the 15 wedges.
5. Hand out the *Wedge Ratings* worksheets to students. Students should read the section on wedges in their student guide and be encouraged to find information on these technologies elsewhere, as well. They should then fill in their worksheets with several advantages and challenges of each wedge. As an option, each student can focus on a subset of the wedges.
6. Students should assign a positive integer from 0 to +3 to rate the advantages of the wedge (+3 representing the greatest advantage and 0 representing the least advantage). The same should be done to rate the challenges of each wedge using negative integers from -3 to 0 (-3 representing the most challenging and 0 representing the least challenging). To determine their Advantage-Challenge score for each wedge, students should add together the advantage rating and the challenge rating. The solutions with the highest Advantage-Challenge scores might be considered the most promising solutions for stabilizing carbon emissions. Instruct students to ignore the letters and symbols listed for each wedge for now. They will become important in the next step. Students can complete all or part of this assignment as homework.

Day Two (45 minutes)

7. Answer any questions that students have related to their research and rating process. Explain to students that the next step is to choose wedges within their teams and build a stabilization triangle.
8. Hand out copies of the *Wedge Table, Wedge Gameboard, Wedge Worksheet,* and *Personal Wedge Guidelines*.
9. Explain to students that in addition to the challenges and advantages they identified, they will have a budget to work with, and so must take costs into account as they choose their wedges.
10. Ensure that students understand the systemic nature of their choices. Their choices will not only affect the issue of climate change, but other issues as well. For instance, if no alternative fuel wedges are chosen, this means that we will still be reliant on petroleum 50 years from now (even if conservation or efficiency wedges are chosen). In their presentation, the team would need to justify their opinion that petroleum will be a cost-effective fuel at that point.
11. Direct students to the columns on their *Wedge Ratings* worksheets where the names of the wedges are listed. Under each name there are anywhere from 1-3 climate bucks ($). Explain that the number of climate bucks indicates the relative expense of implementing that strategy. Tell students that they have a budget of 12 climate bucks to spend on their strategies.
12. Explain to students that the wedges have been grouped into the following sectors:
    - **Electricity (E):** Includes technologies and practices that produce or conserve electricity.
    - **Heat (H):** Includes technologies and practices that produce or conserve heat for direct use, such as heating a building, heating water, or providing heat for industries such as steel and aluminum.
    - **Transportation (T):** Includes all modes of transportation and strategies to reduce the energy we consume through transportation.
    - **Biostorage (B):** Plants and soils store carbon. These strategies increase the Earth's capacity to remove carbon from the atmosphere or limit the amount of carbon released from plants and soils through our activities.
13. Explain that the following limits must be observed:
    - Because of the relative amounts of carbon emitted by our "E", "H", and "T" activities, there are limits on the number of wedges that can be used from each of these sectors. Limits for 2060 are based on the current percentage contributions of heat, electricity, and transportation to global carbon emissions. Because of the limits on land available for

Wedge Sectors and Limits



biostorage, there are limits on "B" wedges as well. Students must stay within the limits set on total number of wedges from each sector. Limits are as follows:

- E – 6 wedges
- H – 5 wedges
- T – 5 wedges
- B – 3 wedges

- Display the pie chart above (available as a master on page 88) for students, so they can see how many wedges they can use from each sector.
- Some individual wedges may have limits as well. See the *Wedge Table*. List these wedges and their limits on the board for all students to see.
- Each wedge strategy requires a tremendous amount of change and sometimes a tremendous amount of resources. When a wedge strategy is used more than once, justification must be given as to why the team believes this is possible or desirable.

14. Explain that if a wedge is listed as being part of more than one sector, they can choose one sector to apply it to. The exception is the Building Efficiency wedge, which requires ½ of an H wedge and ½ of an E wedge. This is because in order to obtain a full wedge from increasing the efficiency of our buildings, it is necessary to apply increases in both heating efficiency (i.e., more efficient furnaces, building weatherization) and electricity efficiency (i.e., more efficient refrigerators, smart power strips, etc.). If this strategy is chosen and they end up a half wedge short at the end, a half of any allowable wedge may be used for the full required cost.

15. Students meet in their groups and share their wedge ratings. Based on their ratings, the sector and wedge limitations, and their budget, they should reach agreement on the wedges they would choose. Explain that whenever a wedge is chosen, the team should consider the implications of that choice. For instance, if they choose a synfuels wedge they have chosen to increase our reliance on coal. They should consider our ability to provide this coal while still providing electricity economically. Students should consider the implications of their choices and be ready to incorporate their reasoning in their presentation.

16. Each team should use their *Wedge Worksheet* to ensure that they have stayed within the constraints of the game and to tally their costs. Direct students to the bottom of their worksheets. Instruct them to use the scoring table to predict how different interest groups would rate their wedge on a scale from one to five. Explain the importance of this step by emphasizing to students that their plan does not only need to be effective and affordable, but it has to be acceptable enough to society to be implemented. Stress that there is no right answer, and they are not necessarily looking for the cheapest solution, but the best balance of environmental, economic, and social impacts. Their predictions should be included as part of their presentation.

17. Reviewing the triangle: Each team should review the strengths and weaknesses of its strategies in preparation for reporting and defending its solutions to the class. As part of this process, students can be questioned about their choices.

18. Remind students that the stabilization triangle is designed to stabilize our CO_2 emissions at the level they are at today. However, in order to stabilize our climate, we will need to further reduce our emissions. Now explain to students that to stabilize the concentration of CO_2 in the atmosphere, our carbon emissions must be reduced to match the capacity of the ocean and land biosphere to take up carbon, making net carbon emissions zero. The current uptake by natural sinks is about four GtC/yr. It is important for students to realize that the exercise only takes us part of the way to a solution. See the extension, *Wedge Intensification Worksheet,* to bring students further on the path to an overall solution.

Day Three (45 minutes)

19. Each team prepares a five minute presentation on their process and their product. The presentations should highlight the choices they made and why the team thinks they have come up with an effective solution. Students should be encouraged to use their creativity in designing their presentations. The use of display boards, power point, skits, and songs should be encouraged. Encourage students to utilize elements of art, music, and theater to liven up their presentations and increase their effectiveness.

Day Four (45 minutes)

20. Each team delivers its presentation.

21. Processing**:** In addition to addressing the game and lessons learned, discussion questions are provided below that provide an opportunity to develop and assess the students' understanding of the wedges concept and its applications.

    a. Explain the process your team went through to choose your strategies. How were decisions made? Were there any disagreements? How were they resolved?

b. Was efficiency and/or conservation important to your overall strategy? Why or why not?

c. While this challenge was focused on the issue of climate change, it is important to consider solutions systemically. Did you consider the impacts of your choices on the economy and on other environmental concerns? What about social impacts?

d. Industrialized countries and developing countries now each contribute about half the world's emissions, although the poorer countries have about 85 percent of the world's population. (The U.S. alone emits one-fourth of the world's CO_2.) If we agree to freeze global emissions at current levels, that means if emissions in one region of the world go up as a result of economic/industrial development, then emissions must be cut elsewhere. Should the richer countries reduce their emissions 50 years from now so that extra carbon emissions can be available to developing countries? If so, by how much?

e. Through discussion, ensure students understand that any of their stabilization triangles represents a revolutionary change in how we produce and consume energy that will require substantial investments and require an unprecedented amount of international cooperation.

Variations

As an option, you can produce copies of each team's gameboard and provide copies to each individual student. Students should then review the gameboards and choose what they think are the two most promising strategies. As a writing assignment, students can make the case for their selections. After collecting the papers, tally up the votes to determine the strategy most favored by the class.

As another option, you can appoint judges to choose what they feel is the most effective strategy. In CMI workshops, the teams' triangles have been judged by experts from various global stakeholder groups, such as an environmental advocacy organization, the auto industry, a developing country, or the U.S. Judging ensures that economic and political impacts are considered and emphasizes the need for consensus among a broad coalition of stakeholders. For a classroom, judges can be recruited from local government, colleges, businesses, and non-profit organizations, or a teacher/facilitator can probe each team about the viability of its strategies.

Extension: Wedge Intensification

✔ Procedure

1. Remind students that the stabilization triangle is designed to stabilize our CO_2 emissions at the level they are at today. However, in order to stabilize our climate, we will need to further reduce our emissions. Now explain to students that to stabilize the concentration of CO_2 in the atmosphere, our carbon emissions must be reduced to match the capacity of the ocean and land biosphere to take up carbon, making net carbon emissions zero. The current uptake by natural sinks is about four GtC/yr.

   The goal of the "flat path" exercise was to stabilize CO_2 in the atmosphere by first freezing emissions at current levels for 50 years, then reducing emissions later in the century to match natural sinks. The resulting concentration of CO_2 in the atmosphere is projected to be ~500 ppm.

   Explain that recently, though, many scientists have been calling for a tougher target of 450 ppm CO_2 equivalent, to keep warming below two degrees Celsius. For example, in July 2008 the leaders of the G8 nations (Group of Eight Nations—Canada, France, Germany, Italy, Japan, Russia, the United Kingdom, the United States, and the European Union) proposed cutting global greenhouse gas emissions by 50 percent from current levels by the year 2060. For CO_2, meeting this goal would require getting emissions down to the level of natural sinks by 2060, requiring about another four wedges of carbon mitigation if we started today (see *Stabilization Wedges*, page 87). Emissions would still have to continue to decline after 2060, though much more slowly than in the flat path scenario, as natural sinks' uptake of carbon is expected to gradually wane.

   How would your group pursue this tougher target? What strategies would you use for the additional four wedges?

2. Direct students to the *Intensification Wedge* board. Explain that they can now choose four wedges in addition to those selected previously. They are still subject to the same limits and rules for using wedges; however, in this segment, they now have an additional eight climate bucks to use. When their *Intensification Wedge* is complete, they can cut out the wedge and tape it to the bottom of their original wedge.

3. Each team should use their *Wedge Intensification Worksheet* to ensure they have stayed within the constraints of the game and to tally their costs. Have students re-visit the scoring table at the bottom of their *Wedge Worksheets* and decide if their actions in this segment would change their predicted scores.

4. Students should be encouraged to use strategies not listed in their solutions, if they can provide justification that their strategy can produce a wedge worth of emissions cuts by 2060.

Extension: Personal Wedges

✔ Procedure

1. Explain to students that they can develop "personal wedges", finding ways to make their individual contribution to carbon reductions. In order to stabilize carbon emissions, it will be necessary to reach a target of one ton/person/year of carbon, on average. Currently, North Americans are responsible for five tons/person/year, while many people elsewhere in the world use far less than one ton per year.
2. Instruct students to research behaviors and their potential impacts. To reduce emissions by four tons/year to reach the global average target, students can create eight half ton (1,000 pounds) wedges analogous to the global wedges in the previous exercise.
3. Direct students to their *Personal Wedge Guidelines* (pages 85-86) and review how to calculate personal wedges. One approach to determining personal wedges is to use one of the many online carbon footprint calculators available. One is available through the EPA at http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html. If possible, project the website on a screen and work through an example. The site will provide an estimate of how much carbon they would keep out of the atmosphere through personal actions. They will need to provide the following information:
   - number of people in their household;
   - what fuel they use to heat their home;
   - miles/year driven by their family (estimate);
   - average gas mileage of their family's vehicles (go to http://www.fueleconomy.gov/ to research mileage of specific vehicles);
   - amount of their average gas and electric bill; and
   - what waste they recycle.

   Important: The calculator will provide their CO_2 emissions, but wedges are based only on the carbon in the CO_2. To determine the amount of carbon emissions based on CO_2 emissions, multiply by 0.2727.
4. Direct students to their *Personal Wedge Gameboard* (page 89) and make sure that students understand the wedges are worth ½ ton in this round, rather than one billion tons as they were in the original version. Because the boards are the same shape, the same wedge pieces can be used.
5. Implementing eight personal wedges is a challenging task—ask students how likely they are to implement the changes in their personal triangles. If not likely, how are we going to reach the one ton/person/year target?

As an option, students can do further research that answers more in-depth questions. Some suggested questions are given below:

"T" Wedges

- What mass transit strategies could be used?
- How would the design of cities and towns need to change?
- What technologies make it feasible to double the mileage of vehicles?

"H" Wedges

- What technologies are available that would allow buildings to increase their efficiency to this extent?
- How would you persuade builders to build more efficiently?
- Research the LEED program and explain how it could help provide another wedge.
- What are "zero energy buildings"? Explain how these could help provide another wedge.

"E" Wedges

- What technologies are available to double the efficiency of power plants?
- What areas hold the most promise for underground carbon dioxide storage? Why?
- What changes will be needed in our infrastructure to fuel our vehicles with hydrogen? Who would pay for these changes?
- Using synfuels to generate electricity will increase our reliance on coal. Explain why you think there will be enough supplies to provide electricity economically.
- What would your plan be for securely storing and transporting radioactive waste?
- Solar electricity is more expensive than any of the other E wedges. How would you pay for these additional costs? Or, how would you make the price more competitive?

"B" Wedges

- How is ethanol made?
- How would you address potential impacts on food costs and biodiversity?
- Currently, we are losing forests - primarily in the tropics. Why? What can be done about this?
- What techniques are used to minimize carbon releases from the soil?
- Every extra wedge requires adding forests within an area of the U.S. Is there enough un-forested land in the world to do this?

Wedge Challenge
Student Guide

Mitigation: Technological Solutions

There are many strategies available that we can employ as a world community to reduce greenhouse gases (GHGs) in the atmosphere. There are many promising new technologies that can be employed, in addition to those that exist today. The existing strategies fall into these categories:

- Energy Efficiency and Conservation
- Switching Fuels
- Carbon Capture, Utilization, and Storage
- Enhancing Natural Sinks

Energy Efficiency and Conservation

There are many opportunities for reducing emissions by increasing efficiencies in the three major sectors of the energy economy—electricity production, transportation fuels, and direct use of fuels in residences and industry. Energy efficiency is the most cost-effective way to reduce GHG emissions. It has already made huge contribution. From 1973 to 1986 the U.S. economy grew by 36 percent without an increase in energy use. Without these gains in efficiency we would now have 250 additional power plants and be emitting 1.5 times more CO_2. Even with these gains, however, there are still vast opportunities. According to the U.S. EPA, our nation's buildings still use 30 percent more energy than they need to. These savings can be had simply by using existing technology.

Switching Fuels

While conservation and efficiency can make an important contribution, they cannot, alone, mitigate climate change. The fuels we use to generate electricity, provide transportation, and heat our homes, are primarily carbon-based today. By switching to fuels that contain less carbon or emit no carbon at all, we can make significant cuts in GHG emissions.

Carbon Capture, Utilization, and Storage (CCUS)

In this strategy, CO_2 is separated from the other products of combustion at a power plant or other facility. The CO_2 is concentrated and sent to a destination other than the atmosphere. The most promising storage scenario is geological storage, in which the CO_2 is placed deep underground. Alternate carbon storage ideas include storage deep in the ocean and storage of carbon in solid form as carbonates.

CCUS has the potential to be implemented wherever there are large point sources of CO_2, such as at power plants and refineries. The storage space available below ground is probably large enough to make carbon capture and storage a compelling mitigation option. There are still questions as to how effective and how costly this strategy will be.

CCUS is currently being used on a large scale at seventeen locations. Norway pioneered the technology at the Sleipner oil and gas field in the North Sea since 1996. Every year the project, run by state–controlled utility Statoil, injects nearly one million tons of CO_2 into saline aquifers 1,000 meters beneath the sea bottom. To date, over 16 million tons of CO_2 have been injected for storage.

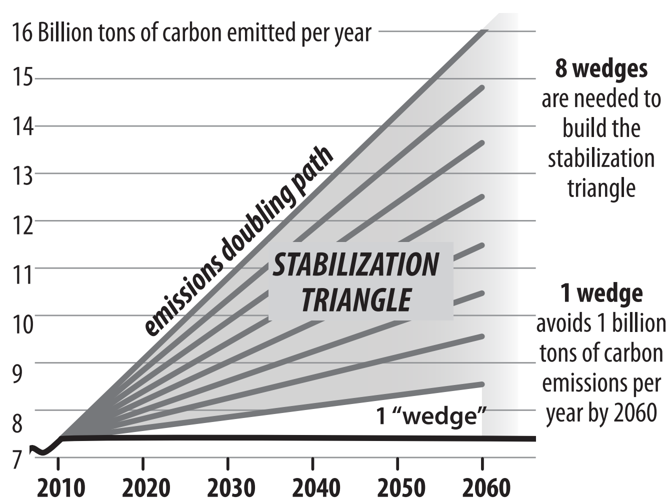
Three large-scale CCUS facilities are currently operating in the U.S. Located in Texas, Oklahoma, and Wyoming, these facilities capture carbon dioxide and transport it by pipeline to enhance oil recovery in depleted fields and in the production of fertilizer.

Enhancing Natural Sinks

A natural **carbon sink** is another word for a carbon reservoir. Land plants store huge amounts of carbon, so fostering that sink by creating forest plantations and limiting **deforestation** can combat the emissions humans release into the atmosphere. Conservation tillage, in which farmers use practices designed to avoid carbon loss from soils, also has the potential to provide substantial emissions reductions if used around the globe.

The Wedge Concept

Because the demand for energy is expected to rise 50 percent over the next 50 years, keeping carbon emissions flat will require cutting projected carbon output by about 8 billion tons per year by 2060, keeping a total of about 200 billion tons of carbon from entering the atmosphere. This carbon savings is what we call the "stabilization triangle". We have divided the stabilization triangle into eight "wedges." A wedge represents a carbon-cutting strategy that has the potential to grow from its present level of use to avoiding an additional 1 billion tons of carbon emissions per year by 2060, or



one-eighth of the stabilization triangle. Fifteen strategies have been identified that could provide a wedge. Each wedge falls into one or more of the following sectors:

- Electricity
- Transportation
- Heat
- Biostorage

Each of these wedges are described below.

Energy Efficiency and Conservation Wedges

Transportation Efficiency

Today there are over one billion cars in the world, and it is predicted that there will be 2.5 billion passenger vehicles on the road by 2050. Efficiency improvements could come from using hybrid and diesel engine technologies, as well as making vehicles out of strong but lighter-weight materials.

Cutting carbon emissions from trucks and planes by making their engines more efficient can also help. Aviation is the fastest growing mode of transportation today.

Doubling the fuel efficiency of all the cars projected for 2060 from 30 mpg to 60 mpg.

TRANSPORTATION EFFICIENCY

Transportation Conservation

By driving less, tremendous emissions savings are possible. We can achieve this by choosing to take public transportation or utilize strategies such as telecommuting or teleconferencing. To make this possible for more drivers, municipalities can expand opportunities for carpooling and public transportation.

A 50 percent reduction in miles traveled by the world's cars will require building more mass transit and improvements to communications networks.

TRANSPORTATION CONSERVATION

Efficiency in Buildings

Today carbon emissions arise about equally from providing electricity, transportation, and heat for industry and buildings. The largest potential savings are in space heating and cooling, water heating, lighting, and electric appliances. It is projected that the buildings sector as a whole has the technological and economic potential to cut emissions in half.

Cutting emissions by 25% in all new and existing residential and commercial buildings by using more efficient appliances, lighting, insulation, and heating and cooling technology.

EFFICIENCY IN BUILDINGS

Carbon savings from space and water heating can be achieved with strategies such as adding insulation and air sealing, as well as installing solar water heating and using passive solar design. Savings can also be achieved from the use of more efficient appliances and lighting.

Electricity Generation Efficiency

Today's coal-fired power plants produce about one-fourth of the world's carbon emissions and operate at about 35 percent efficiency, so increasing their efficiency can significantly reduce emissions. Efficiency can be increased by installing new turbines, using high-temperature fuel cells, and combining fuel cells and turbines. Other strategies include **cogeneration** and **polygeneration**.

Due to contributions by renewable energy sources and nuclear energy, the electricity sector already generates about 30 percent of its energy from non-carbon sources.

Producing the world's projected coal-based electricity with increased efficiency (increasing from 40% to 60%).

ELECTRICITY GENERATION EFFICIENCY

Switching Fuels Wedges

Natural Gas

The combustion of natural gas for electricity and heat produces about half the emissions of coal used for the same purposes, so replacing coal with natural gas can provide substantial emissions reductions.

1,100 large (1 billion watt) natural gas plants replacing similar coal plants. Requires generating about four times the Year 2000 global production of electricity from natural gas.

SWITCH FROM COAL TO NATURAL GAS

Uranium

Nuclear fission currently provides about 13.5 percent of the world's electricity, and produces no CO_2. Although nuclear power is currently more expensive than fossil-fuel based electricity, subsidies and high coal and natural gas prices can make this technology economically competitive. Concerns remain, however, about the long-term storage of radioactive waste from nuclear power plants, which remains toxic for thousands of years.

Adding new nuclear electric plants to provide 1.5 times the world's current nuclear capacity, replacing coal plants. Currently there are 449 reactors worldwide, with 99 in the U.S.

NUCLEAR ELECTRICITY

Wind

Wind is a renewable source of energy and is clean, causing no air or water pollution. Wind is free and is an economical energy source for producing electricity. One of the disadvantages of wind energy is that it is dependent on the weather. When there is not enough or too much wind, turbines do not produce electricity efficiently. In some areas, there is concern about birds and bats that may be injured by wind turbines. Some people believe wind turbines produce a lot of sound, and some think they impact their views of the landscape. Thousands of wind turbines have already been installed around the world, with capacity increasing 25-30 percent per each year.

Scaling up current wind capacity by 20 times to replace coal plants (an additional 780,000 wind turbines). This would require an area roughly the size of Germany.

WIND ELECTRICITY

Solar

Photovoltaic (PV) cells convert sunlight to electricity, providing a source of carbon-free, renewable energy. Solar PV capacity has recently been expanding at rates of 30-50 percent a year, but still provides less than 0.1 percent of the world's total energy. Significant emissions reductions would require increasing PV installations by a factor of 700 in the next 50 years or installing PV arrays at 60 times the current rate. A drawback for PV electricity is its price, which is declining, but is still 2-5 times higher than fossil-fuel-based electricity. Like wind, PV is not able to provide power at all times because it requires sunlight.

Scaling up current capacity by 550 times. Arrays would require an area of two million hectares, or 20,000 km^2. This would require an area the size of New Jersey.

SOLAR ELECTRICITY

Hydrogen from Wind

The electricity produced by nuclear plants, wind turbines, or solar PV could also be used to split water molecules to make carbon-free hydrogen for transportation fuel or heat. Hydrogen is a good fuel for a low-carbon society because, when it's burned or used in a fuel cell, the only emission is water vapor. To produce wind–hydrogen, electricity generated by wind turbines is used to power electrolysis, a process that liberates hydrogen from water. Unlike hydrogen produced from fossil fuels, wind–hydrogen could be produced on a small scale where it is needed. Wind–hydrogen would require less investment in infrastructure for fuel distribution to vehicle fueling stations and homes.

1.5 million additional wind turbines to provide hydrogen to replace fossil fuels used in vehicles and buildings. Would require a land area roughly the size of France.

WIND-HYDROGEN

Biofuels

Because plant matter is created by **photosynthesis** using carbon dioxide from the atmosphere, combustion of "**biofuels**" made from plants like corn and sugar cane simply returns borrowed carbon to the atmosphere. This cycle would maintain the balance of CO_2 in the atmosphere, but because of the CO_2 emissions from farming, the ethanol production process, and production of fertilizer and pesticides, corn **ethanol** adds more CO_2 to the atmosphere than it removes. An increased demand for ethanol will likely lead to converting forests and grasslands to crop land for fuel and food. This conversion releases carbon dioxide into the atmosphere. When these factors are taken into account, switching to corn ethanol from gasoline would provide little or no climate change benefit in the next 50 years. By comparison, the production and use of cellulosic ethanol could reduce CO_2 emissions by 18-25 percent compared to gasoline even when the impacts from clearing land for crops are considered. In tropical climates, sugarcane is used as a feedstock for ethanol. Because of its high sugar content, sugarcane yields six times more ethanol than corn for the same amount of energy input. This gives sugarcane environmental and economic advantages over corn ethanol. Brazil now meets most of its transportation fuel needs with sugarcane ethanol. The land constraints for biofuels are more severe than for wind and solar electricity, and can affect food prices.

Increasing today's ethanol production by about 33 times, and making it sustainable. Would have to come from sugarcane not corn. Would use 1/6 of the world's cropland using current practices. This is an area roughly the size of India.

BIOFUELS

Carbon Capture, Utilization, and Storage (CCUS) Wedges

CCUS With Coal Or Natural Gas Electricity

Today's coal and natural gas-burning power plants produce about one-fourth of the world's carbon emissions and are large point-sources of CO_2 to the atmosphere. As with all CCUS strategies, to provide low-carbon electricity, the captured CO_2 would need to be stored for centuries.

Applying CCUS to 600 large (1,000 MW) baseload coal power plants or 1,200 large baseload natural gas power plants in 50 years. Requires storing 3,500 times the capacity of any one of the three existing projects.

CCUS WITH COAL OR NATURAL GAS ELECTRICITY

CCUS with Hydrogen from Fossil Fuels or Coal

Because fossil fuels are composed mainly of carbon and hydrogen they are potential sources of hydrogen, but to have a climate benefit the excess carbon must be captured and stored. Pure hydrogen is now produced mainly in two industries: ammonia fertilizer production and petroleum refining. Today these hydrogen production plants generate about 100 million tons of capturable carbon. Now this CO_2 is vented, but only small changes would be needed to implement carbon capture.

Increasing the amount of hydrogen produced today (from natural gas and/or coal) by ten times to replace fossil fuels used in vehicles and buildings. Requires storing 3,500 times the capacity of any one of the three existing projects.

CCUS WITH HYDROGEN FROM NATURAL GAS OR COAL

Liquid Fuel CCUS for Synfuels

In 50 years a significant fraction of the fuels used in vehicles and buildings may not come from conventional oil, but from coal. When coal is heated and combined with steam and air or oxygen, carbon monoxide and hydrogen are released and can be processed to make a liquid fuel called a **synfuel**.

Coal-based synfuels result in nearly twice the carbon emissions of petroleum-derived fuels, since large amounts of excess carbon are released during the conversion of coal into liquid fuel. The world's largest synfuels facility, located in South Africa, is the largest point source of atmospheric CO_2 emissions in the world.

Capturing an amount of carbon equal to the CO_2 emissions from 180 coal-to-synfuels facilities the size of the largest facility in the world today. Requires storing 3,500 times the capacity of any of the existing projects.

CCUS FOR SYNFUELS

Enhancing Natural Sinks Wedges

Forest Storage

Land plants and soils contain large amounts of carbon. Today, there is a net removal of carbon from the atmosphere by these "natural sinks," in spite of deliberate deforestation by people that adds 1–2 billion tons of carbon to the atmosphere. Land plant biomass can be increased by both reducing deforestation and planting new forests (**reforestation**).

Halting global deforestation in 50 years OR establishing new forests over an area the size of the contiguous United States.

FOREST STORAGE

Soil Storage

Conversion of natural vegetation to cropland reduces soil carbon content by one-half to one-third. However, soil carbon loss can be reversed by agricultural practices that build up the carbon in soils, such as conservation tillage. The term conservation tillage refers to a number of strategies and techniques for establishing crops in a previous crop's residues, which are purposely left on the soil surface. In addition to improving water conservation and the reduction of soil **erosion**, these techniques reduce the amount of carbon that is lost to the atmosphere from the soil.

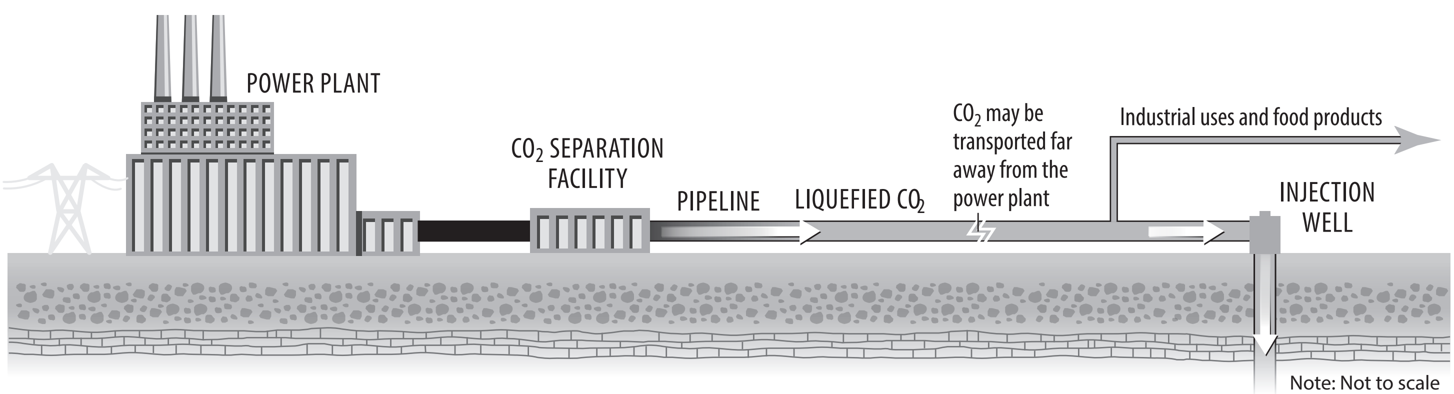
Other ways to reduce these carbon transfers include planting cover crops (crops that are planted to help enrich the soil but are not harvested for food) and reducing the period of time that a field lays bare.

Applying carbon management strategies to all of the world's existing agricultural soils.

SOIL STORAGE

Carbon Capture, Utilization, and Storage Overview

Carbon dioxide from a power plant or industrial facility will be separated from other flue gases at a separation facility on site. It will then be pressurized into a liquid and transported via pipeline to be used in a new application or in enhanced hydrocarbon recovery. Or, it will be sent underground into a deep saline formation, depleted oil reservoir, or unmineable coal seam.



Wedge Challenge Instructions
Student Guide

Student Game Instructions and Materials

The goal of this game is to construct a stabilization triangle using eight wedge strategies, with only a few constraints to guide you. From the 15 potential strategies, choose 8 wedges that your team considers the best global solutions.

Rate the Wedges

1. **Rate the wedges individually** using the *Wedge Ratings* worksheets. Each team member should read the wedge descriptions and fill in several advantages and challenges presented by each wedge. Then, assign a positive integer from 0 to +3 to rate the advantages of the wedge (+3 representing the greatest advantage 0 representing the least advantage). The same should be done to rate the challenges of each wedge using negative integers from -3 to 0 (-3 representing the most challenging and 0 representing the least challenging). To determine your Advantage-Challenge score for each wedge, add together the advantage rating and the challenge rating. The solutions with the highest Advantage-Challenge scores might be considered the most promising solutions for stabilizing the climate.

Build a Group Triangle

2. **Share your wedge ratings** with each other and discuss their relative challenges and advantages. You have a budget of 12 climate bucks and you have limits on how many wedges you can use from each sector.
3. **Find the Wedge Gameboard** and cut apart the red, green, yellow, and blue wedge pieces supplied (if not already done for you).
4. **Choose Wedge Strategies:** Reach a decision as a team on one wedge strategy at a time to fill the 8 spots on the *Wedge Gameboard*. The four colors of the wedge pieces indicate the sector; transportation (blue), heat (yellow), electricity (red), and biostorage (green). Choose a red, yellow, blue, or green wedge for your strategy, then **label the wedge to indicate the specific strategy.** Read the questions for each wedge chosen on the *Wedge Table* and fill in your answers on the *Wedge Worksheet*. Use a separate sheet of paper if more space is needed.
5. **Most strategies may be used more than once, but not all strategies can come from one energy sector.** Also, the cost of many wedges increases as more are used (see the *Wedge Table*). Of the 16 billion tons of carbon emitted in the 2060 baseline scenario, we assume electricity production accounts for 6 wedges, transportation fuels account for 5 wedges, and direct fuel use for heat and other purposes accounts for 5 wedges. Because of the limits on land available for biostorage, there is a limit of 3 "B" wedges.

Analyze and Explain Your Strategy

6. For each of the 8 strategies chosen, each team should **fill out one line in the *Wedge Worksheet***. After all 8 wedges have been chosen, tally total cuts from each energy sector (electricity, transportation, heat, and biostorage) and costs. Use the scoring table to predict how different interest groups would rate your wedge on a scale from 1 to 5.
7. Each team should **give a 5-minute oral report** on the reasoning behind its triangle. The report should justify your choice of wedges to the judge(s) and to the other teams.

Note: There is no "right" answer.

How Much is a Wedge Worth?

A wedge of any strategy replaces:

- 550 gigawatts (GW) of coal-based electricity (or 1,400 GW natural-gas based electricity),

OR

- 330 billion gallons of gasoline or heating oil,

OR

- 1.3 billion tons (or 190 billion cubic feet) of natural gas.

Wedge Ratings

	TRANSPORTATION EFFICIENCY $ T	TRANSPORTATION CONSERVATION $ T	EFFICIENCY IN BUILDINGS $ H, E
One Wedge Equals...	Doubling the fuel efficiency of all the cars projected for 2060 from 30 mpg to 60 mpg.	A 50 percent reduction in miles traveled by the world's cars will require building more mass transit and improvements to communications networks.	Cutting emissions by 25% in all new and existing residential and commercial buildings by using more efficient appliances, lighting, insulation, and heating and cooling technology.
Advantages			
Challenges / Costs			
Advantages Rating (0-3)			
Challenges Rating (-3 - 0)			
Score (Advantages – Challenges)			

Wedge Ratings

	ELECTRICITY GENERATION EFFICIENCY $ E	ELECTRICITY—SWITCH FROM COAL TO NATURAL GAS $ E	NUCLEAR ELECTRICITY $$ E	WIND ELECTRICITY $$ E
One Wedge Equals...	Producing the world's projected coal-based electricity with increased efficiency (increasing from 40% to 60%).	1,100 large (1 billion watt) natural gas plants replacing similar coal plants. Requires generating about four times the Year 2000 global production of electricity from natural gas.	Adding new nuclear electric plants to provide 1.5 times the world's current nuclear capacity, replacing coal plants. Currently there are 449 reactors worldwide, with 99 in the U.S.	Scaling up current wind capacity by 20 times to replace coal plants (an additional 780,000 wind turbines). This would require an area roughly the size of Germany.
Advantages				
Challenges / Costs				
Advantages Rating (0-3)				
Challenges Rating (-3 - 0)				
Score (Advantages – Challenges)				

Wedge Ratings

	SOLAR ELECTRICITY $$$ E	WIND-HYDROGEN $$$ E,T	BIOFUELS $$ H,T	CCUS WITH COAL OR NATURAL GAS ELECTRICITY $$ E
One Wedge Equals...	Scaling up current capacity by 550 times. Arrays would require an area of two million hectares, or 20,000 km^2. This would require an area the size of New Jersey.	1.5 million additional wind turbines to provide hydrogen to replace fossil fuels used in vehicles and buildings. Would require a land area roughly the size of France.	Increasing today's ethanol production by about 33 times, and making it sustainable. Would have to come from sugarcane not corn. Would use ⅙ of the world's cropland using current practices. This is an area roughly the size of India.	Applying CCUS to 600 large (1,000 megawatt) baseload coal power plants or 1,200 large baseload natural gas power plants in 50 years. Requires storing 3,500 times the capacity of any one of the three existing projects.
Advantages				
Challenges / Costs				
Advantages Rating (0-3)				
Challenges Rating (-3 - 0)				
Score (Advantages – Challenges)				

Wedge Ratings

	CCUS WITH HYDROGEN FROM NATURAL GAS OR COAL $$$ H,T	CCUS FOR SYNFUELS $$ H, T	FOREST STORAGE $ B	SOIL STORAGE $ B
One Wedge Equals...	Increasing the amount of hydrogen produced today (from natural gas and/or coal) by ten times to replace fossil fuels used in vehicles and buildings. Requires storing 3,500 times the capacity of any one of the three existing projects.	Capturing an amount of carbon equal to the CO_2 emissions from 180 coal-to-synfuels facilities the size of the largest facility in the world today. Requires storing 3,500 times the capacity of any of the existing projects.	Halting global deforestation in 50 years OR establishing new forests over an area the size of the contiguous United States.	Applying carbon management strategies to all of the world's existing agricultural soils.
Advantages				
Challenges / Costs				
Advantages Rating (0-3)				
Challenges Rating (-3 - 0)				
Score (Advantages – Challenges)				

Wedge Table

Before choosing a wedge, read the instructions for the wedge below.

Only complete wedges may be used, unless:

- you are directed to use a ½ wedge due to the constraints of the game; or
- you need to use a ½ wedge to complete your board.

STRATEGY	COST	LIMITS AND SPECIAL INSTRUCTIONS
Transportation Efficiency	T $	You can only use this wedge once. If you choose this wedge, then the cost of all other "T" wedges is multiplied by 1.5 times.
Transportation Conservation	T $	You can only use this wedge once. If you choose this wedge, then the cost of all other "T" wedges is multiplied by 1.5 times.
Efficiency in Buildings	½ H + ½ E $	You must use ½ of an "H" wedge and ½ of an "E" Wedge.
Electricity Generation Efficiency	E $	If you choose this wedge strategy, then the cost of all other "E" wedges is multiplied by 1.5 times. You may only use this wedge once.
Electricity—Switch from Coal to Natural Gas	E $	If you chose Electricity Generation Efficiency, then each wedge of this you choose costs $$.
Nuclear Electricity	E $$	If you chose Electricity Generation Efficiency, then each wedge of this you choose costs $$$.
Wind Electricity	E $$	If you chose Electricity Generation Efficiency, then each wedge of this you choose costs $$$.
Solar Electricity	E $$$	If you chose Electricity Generation Efficiency, then each wedge of this you choose costs $$$$$ (4½$).
Wind-Hydrogen	E or T $$$	If you chose Electricity Generation Efficiency, then each "E" wedge of this you choose costs $$$$$ (4½$). If you chose Transportation Efficiency or Conservation, then you can only use this once as a "T" wedge and the cost is $$$$$ (4½$).
Biofuels	H or T $$	If you chose Transportation Efficiency or Conservation, then you can only use this once as a "T" wedge and the cost is $$$
CCUS with Coal or Natural Gas Electricity	E $$	If you chose Electricity Generation Efficiency, then each wedge of this you choose costs $$$.
CCUS with Hydrogen from Natural Gas or Coal	H or T $$$	If you chose Transportation Efficiency or Conservation, then you can only use this wedge once as a "T" wedge and the cost is $$$$$ (4½$).
CCUS Synfuels	H or T $$	If you chose Transportation Efficiency or Conservation, then you can only use this wedge once as a "T" wedge and the cost is $$$.
Forest Storage	B $	There are no limitations.
Soil Storage	B $	You may only use one of these wedges. Since a wedge requires practicing low-carbon farming techniques on all the world's farmland, there is only one wedge available.

Wedge Gameboard

Limits:

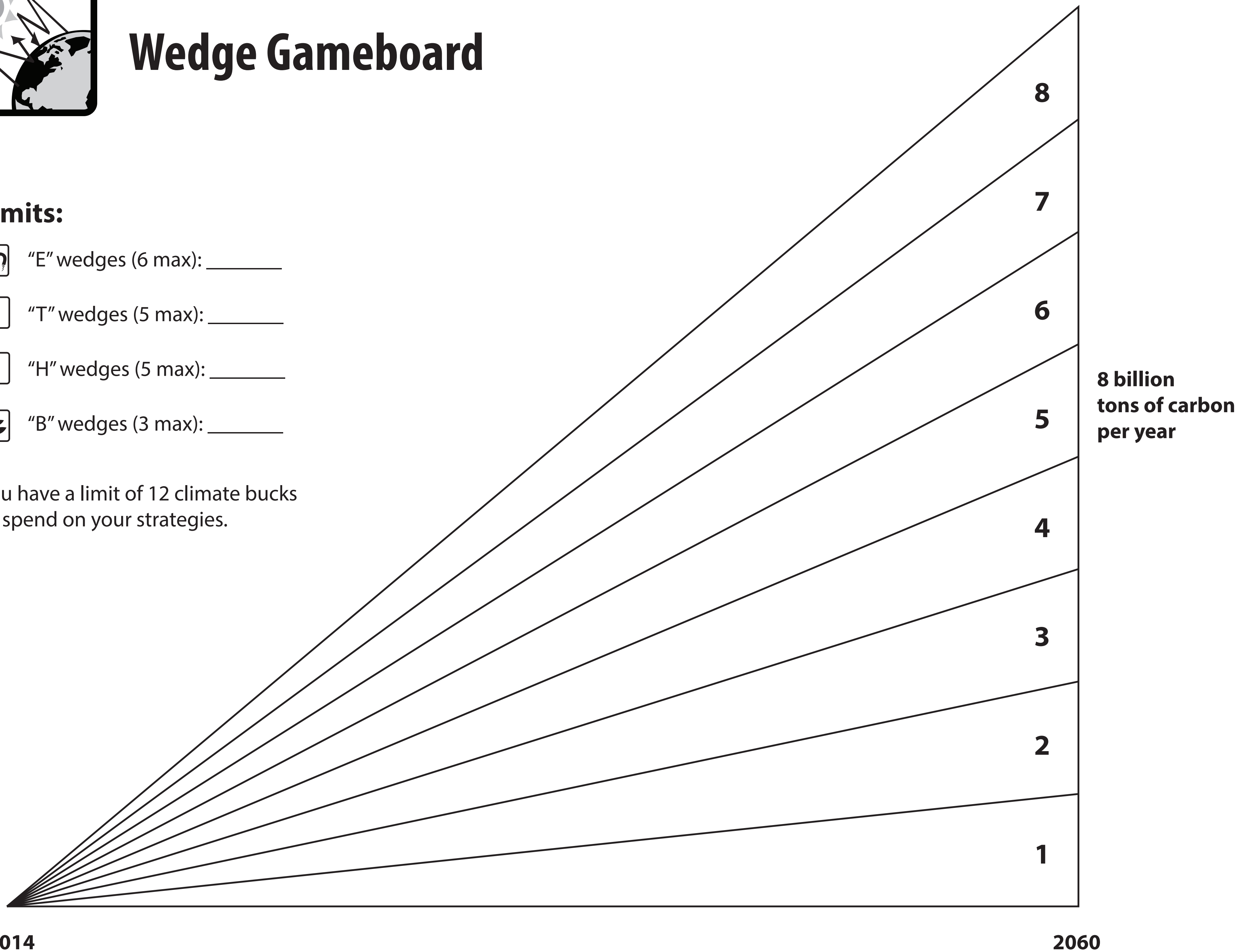
"E" wedges (6 max): ________

"T" wedges (5 max): ________

"H" wedges (5 max): ________

"B" wedges (3 max): ________

You have a limit of 12 climate bucks to spend on your strategies.



Wedge Worksheet

Guidelines:

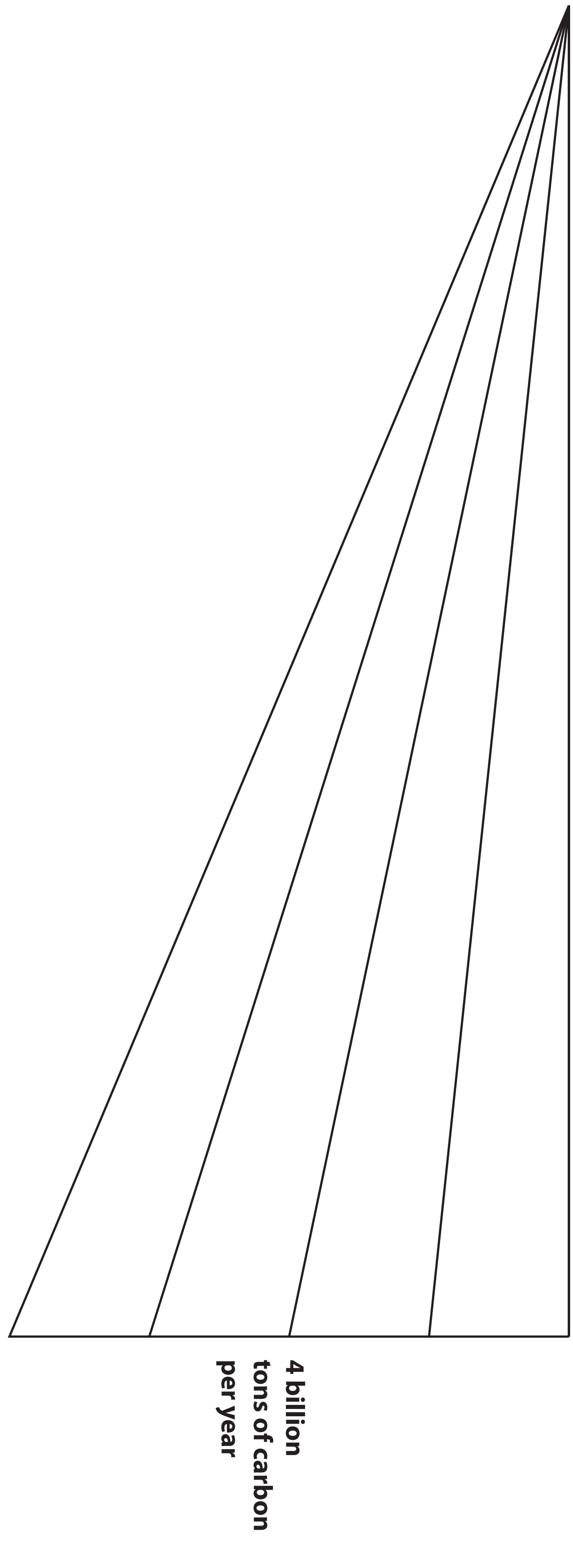
- A strategy may be used more than once if allowed (see *Wedge Table*). You must justify this decision in the last column.
- Only complete wedges may be used, unless:
  - you are directed to use a ½ wedge due to the constraints of the game (to indicate a ½ wedge, list two wedges on the same line. Note: You must use the full cost for a ½ wedge); or
  - you need to use a ½ wedge to complete your board.

	STRATEGY	SECTOR (E, H, T, OR B)	COST	CHALLENGES
1				
2				
3				
4				
5				
6				
7				
8				
	Totals	E= ______(6 max) H= ______(5 max) T= ______(5 max) B= ______(3 max)	(12 max)	

How would each of these groups rate your proposal on a scale of 1-5?

	TAXPAYER/ CONSUMERS	ENERGY COMPANIES	ENVIRONMENTAL GROUPS	MANUFACTURERS	INDUSTRIALIZED COUNTRY GOVERNMENTS	DEVELOPING COUNTRY GOVERNMENTS	TOTAL
Score							

Intensification Wedge



Wedge Intensification Worksheet

Guidelines:

- A strategy may be used more than once if allowed (see *Wedge Table*). You must justify this decision in the last column.
- Only complete wedges may be used, unless:
    - you are directed to use a ½ wedge due to the constraints of the game (to indicate a ½ wedge, list two wedges on the same line. Note: You must use the full cost for ½ wedge); or
    - you need to use a ½ wedge to complete your board.

	TOTAL WEDGES	WEDGES USED ALREADY	WEDGES LEFT TO USE
E	6		
H	5		
T	5		
B	3		

	STRATEGY	SECTOR (E, H, T, OR B)	COST	CHALLENGES
1				
2				
3				
4				
	Totals	E= ______(6 max) H= ______(5 max) T= ______(5 max) B= ______(3 max)		

Personal Wedge Guidelines

One approach to determining your personal wedges is to use one of the many online carbon footprint calculators available. One is available through the EPA at http://www3.epa.gov/carbon-footprint-calculator/. It will provide an estimate of how much carbon you will keep out of the atmosphere through personal actions. You will need to provide the following information:

- number of people in your household;
- what fuel you use to heat your home;
- miles/year driven by your family (estimate);
- average gas mileage of your family's vehicles (go to http://www.fueleconomy.gov/feg/findacar.shtml to find out your mileage);
- amount of your average gas and electric bill; and
- what waste you recycle.

Important: The calculator will provide your CO_2 emissions, but wedges are based only on the carbon in the CO_2. To determine the amount of carbon emissions based on CO_2 emissions, multiply by 0.2727.

Below are some examples of ways to create personal wedges (all calculations were made from U.S. EPA data and formulas).

To calculate your actions individually, you can use the information below as a starting point.

Transportation

Every gallon of gasoline releases about 5 pounds of carbon. What is the average mileage of your family car? To find out, you can visit the EPA's Fuel Economy website at http://www.fueleconomy.gov/feg/findacar.shtml. Once you know your car's gas mileage you can then figure out how many miles per year and pounds of carbon you could save by:

- Biking
- Walking
- Taking public transportation
- Combining trips

About 188.7 gallons are needed for a ½ ton (1,000 pound) wedge.

Electricity

Every kilowatt-hour (kWh) of electricity releases an average of 1.5 pounds of carbon dioxide. This number could be higher or lower depending on how your electricity is generated. One kWh is consumed if ten 100 watt light bulbs are on for an hour. Decreasing your consumption by about 675 kWh per year would provide a ½ ton wedge. Here are a few ways to get there:

- Replace five 60W incandescent bulbs with 800 lumen compact fluorescents (lights on 4 hours/day)—save about 440 pounds of carbon emissions per year.
- Reduce the on-time of your TV by two hours/day (200 watt TV) – save about 233 pounds of CO_2 emissions per year.
- Air dry clothing or dry full loads to reduce the overall number of dryer loads. Eliminating 1 dryer load of laundry per week saves about 450 pounds of CO_2 emissions per year (5400 watt electric clothes dryer).

To figure out how much you can save by reducing the use of appliances or replacing appliances with more efficient models, use the *Plug Loads* guide and spreadsheet available at www.NEED.org.

Important: The Plug Loads Spreadsheet will provide your CO_2 emissions, but wedges are based only on the carbon in the CO_2. To determine the amount of carbon emissions based on CO_2 emissions, multiply by 0.2727.

Heating

If you heat your house or your hot water with natural gas, then you also have great opportunities to save. Natural gas is measured in either therms or hundreds of cubic feet (Ccf). One Ccf is equal to about one therm (1.037). Every therm of natural gas burned releases about six pounds of carbon into the atmosphere. Every gallon of oil burned for heating your home releases about seven pounds of carbon. The first step is to look at your utility bills and see how many therms or gallons you use in a year. Then you can figure out how much you can save by using these figures:

- For every degree you set your thermostat lower than you do now, you can reduce your consumption (and your carbon emissions) by about three percent. For instance, if you currently use 1,000 therms/year and keep your thermostat at 72°F at all times and you lower it to 71°F, then you would only use 970 therms. This would save 180 pounds of carbon.
- If you keep your heat at the same temperature at all times, you can save by turning it down when the house is empty and when everyone is asleep. If you turn your heat down by one degree for 100 hours/week (8 hours/day every weekday when everyone is at school or work and 8 hours every night when everyone is asleep), you can reduce your fuel use by one percent.
- If your water heater is set too high, you can save here as well. Every two degrees you lower the temperature would save about 1 percent of the energy used to heat your water. For an average home that equates to about 16 pounds of carbon if using natural gas. If you heat your water with electricity, then each two degrees you lower the temperature eliminates 32 pounds of carbon emissions. Either way, you will need to measure your water temperature at a faucet. After lowering the thermostat on the water heater, check it again to see how much the temperature decreased (allow several hours before checking).

Cooling

Air conditioning America's homes can account for around 20 percent of total residential electricity consumption. Determining your cooling savings is even trickier than heating. To determine personal wedges from AC savings, use the EPA's carbon footprint calculator mentioned on the previous page.

Biostorage

Trees absorb carbon from the atmosphere through the process of photosynthesis. By planting trees, you can effectively take some of the carbon emissions you produce out of the atmosphere to help create personal wedges. Estimates for how much carbon can be absorbed by a tree vary widely and depend on the species of tree and local climate. Also, a mature tree will take more carbon out of the atmosphere than a sapling just planted. Assuming a conifer tree is planted, the tree will eventually absorb 13 pounds of carbon per year. You would need to plant almost 80 trees in order to make a wedge.

The Trouble With Figuring Out Personal Heating and Cooling Wedges

In most climates, you can make the biggest difference in your carbon footprint by decreasing the amount of energy you use to heat or cool your house. However, determining what actions will add up to a personal wedge is difficult because there are so many variables. These include:

- the size of your house;
- how cold your climate is;
- how old and how efficient your furnace or air conditioner is;
- the degree to which your house is insulated and air-sealed; and
- the extent to which you use natural gas for other uses such as water heating, cooking, and clothes drying.

To get an idea of how much you can save, use the instructions in this section; however, be aware that the impacts of your actions could vary widely.

Stabilization Wedges

FIGURE 1

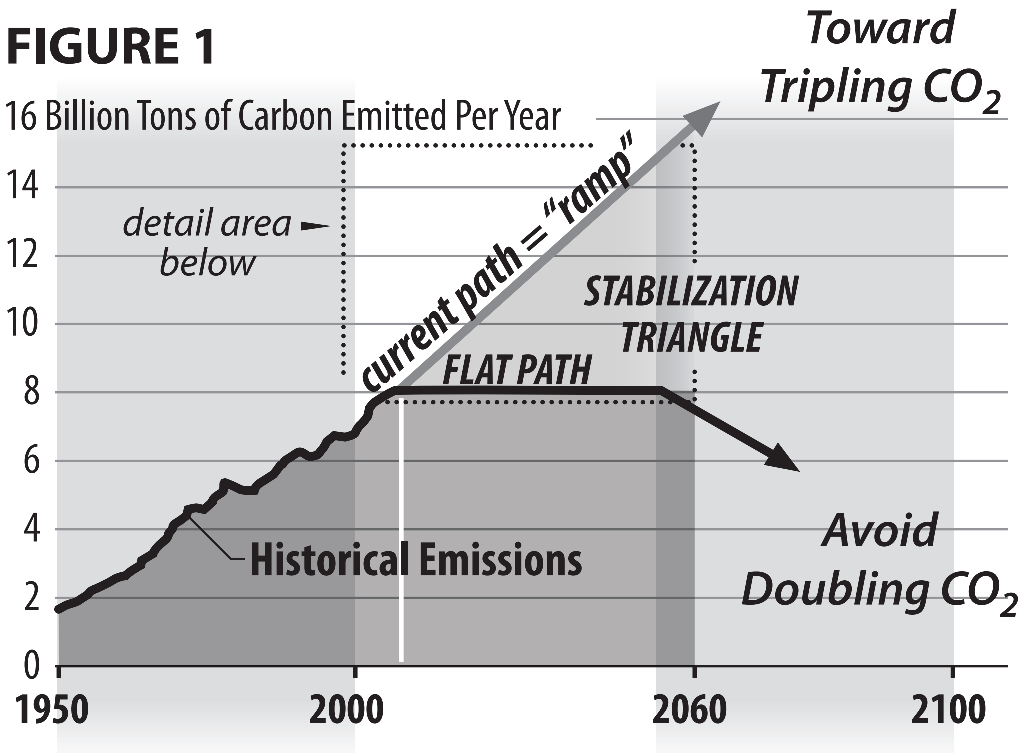
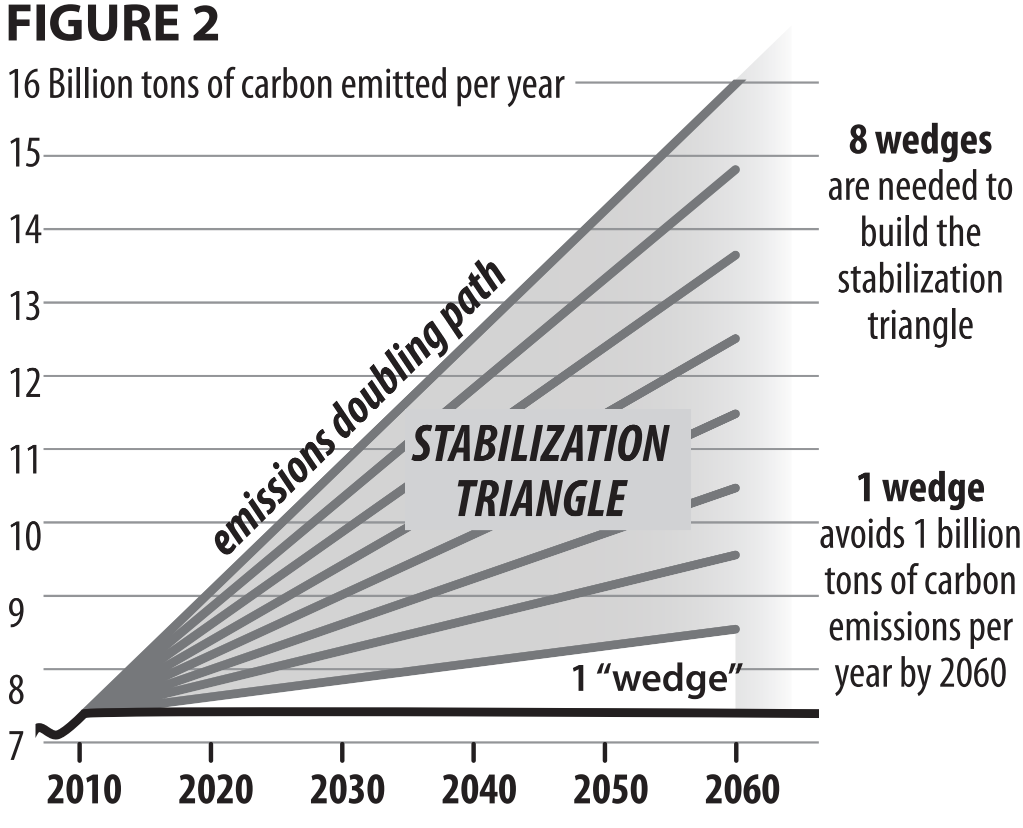
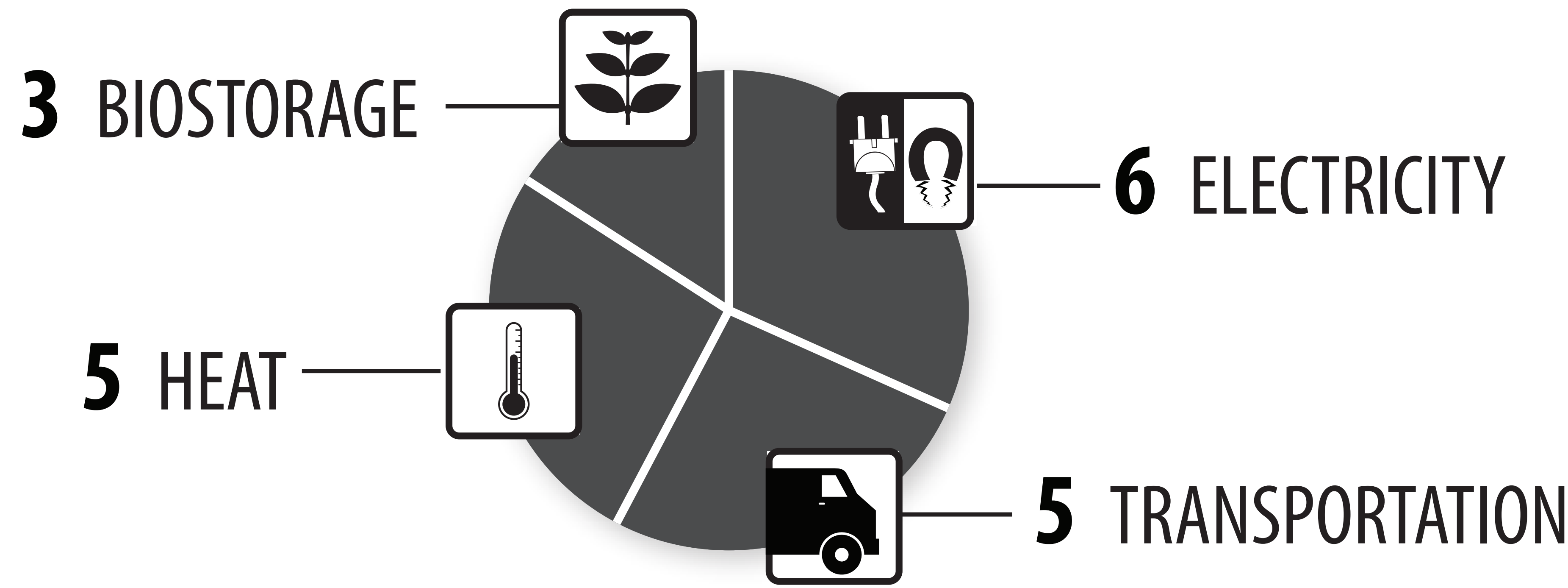


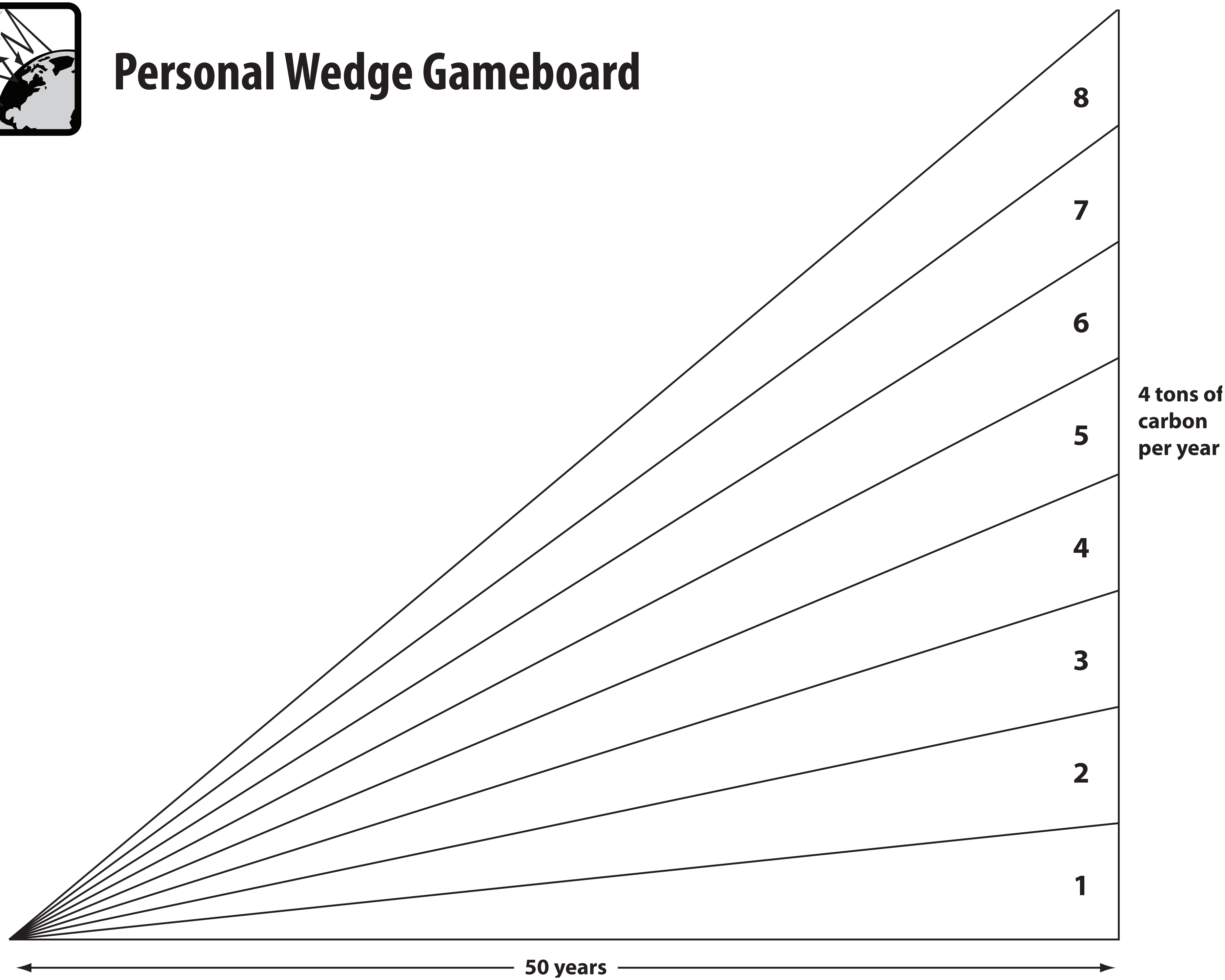
FIGURE 2

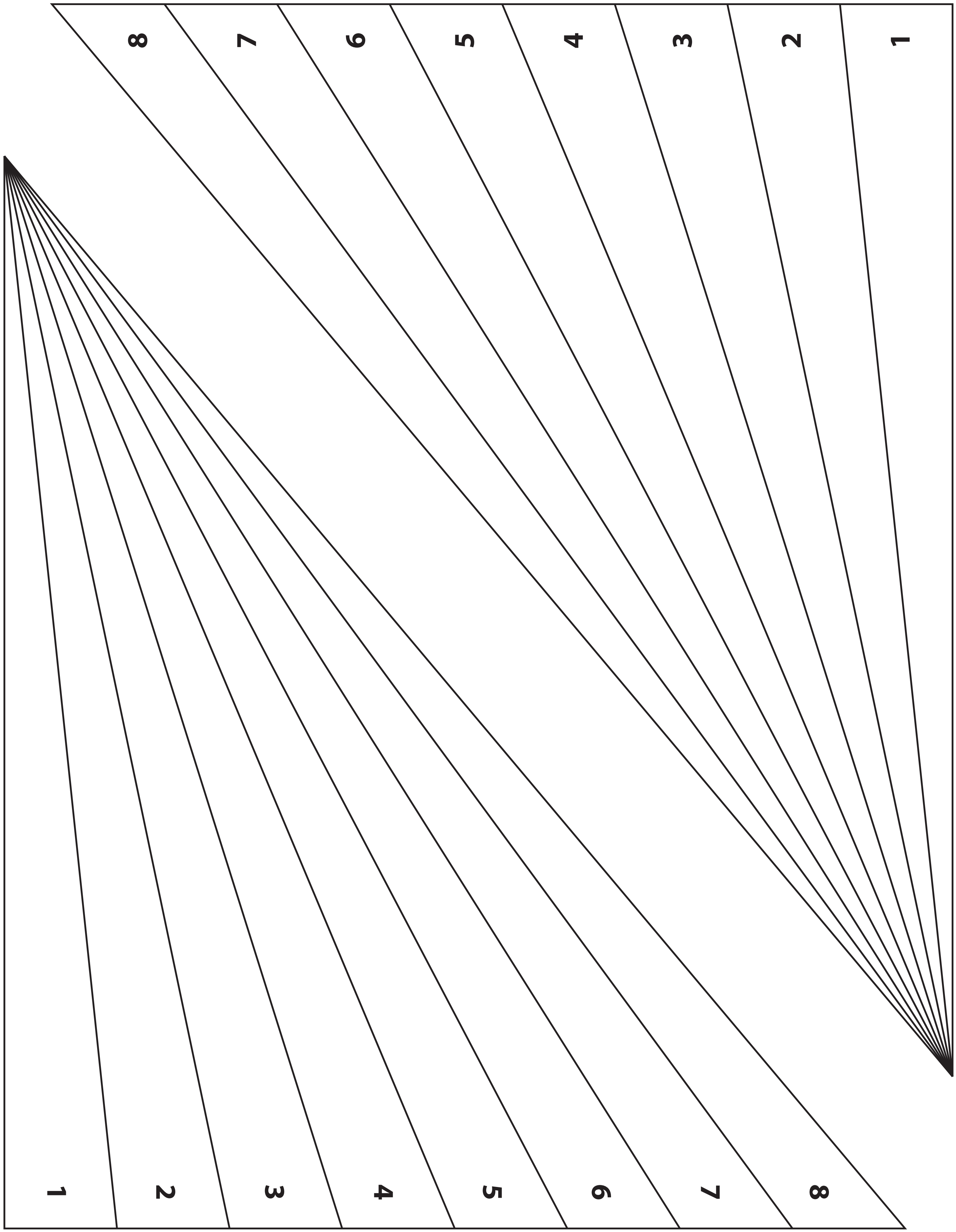


Wedge Limitations



Personal Wedge Gameboard

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Glossary

adapt	to make changes or modifications
aerosols	the suspension of tiny particles or droplets in a gas; smog and volcanic ash are examples
albedo	the ability of any surface to reflect light
atmosphere	the surrounding gaseous state of the air around the Earth
biofuels	fuel considered carbon neutral; biofuels are produced from renewable resources such as vegetable oils, animal fats, and plant biomass
biomass	living organic matter that can be converted to fuel as an energy source
biosphere	the parts of Earth that support life—water, atmosphere, land
British thermal unit (Btu)	a measure of thermal energy (heat); the amount of thermal energy needed to raise the temperature of one pound of water by one degree Fahrenheit; one Btu is approximately equal to the amount of thermal energy released by burning a match
carbohydrates	organic compounds produced through photosynthesis that contain sugar, starch, and cellulose that are consumed by animals for energy
carbon	a basic building block of matter that exists naturally; C on the periodic table of elements
carbon cycle	the organic circulation of carbon atoms in the biosphere exchanged between organisms and the environment
carbon dioxide	an odorless, colorless, noncombustible gas produced from respiration, organic decomposition, and combustion; CO_2
carbon neutral	no carbon dioxide gas production going into the atmosphere
carbon reservoir	area between major carbon sinks including the biosphere, lithosphere, hydrosphere, and atmosphere
carbon sink	a reservoir that accumulates and stores carbon
climate	meteorological conditions in the atmosphere of a certain region over a relatively long period of time including temperature, winds, and precipitation
climatologist	a scientist that works in the field of climatology dealing with climate and climate conditions
climatology	a field of science that deals with climate or climate conditions
cogeneration	generating both heat and electricity simultaneously at a power plant or with a heat engine
combustion	a burning process where a substance reacts with oxygen to emit heat and light
compound	a pure substance formed by combining elements
concentration	the amount of a specific substance within another substance
conservation	saving or preserving to prevent depletion, loss, or extinction
consumption	to use or destroy
convection	the transfer of heat energy through the motion of currents (actual movement of heated material)
cycle	a repeating pattern
deforestation	the clearing or cutting down of trees or forests
degassing	giving off or losing gases
dissolution	the process of being dissolved; becoming incorporated into a gas or liquid
drought	a long period of dry weather with abnormally low precipitation
eccentricity	the amount an orbit deviates from a perfect circle or its shape
electricity	the presence and flow of electric charge, moving electrons
emissions	substances released or emitted into the atmosphere
energy	the ability to produce change or do work

energy consumption	the use of energy by people or devices
energy efficiency	using less energy to produce the same (equivalent) amount of something
energy transformation	any process of energy conversion from one form to another form of energy
erosion	the wearing down of the surface of the Earth by movement from water, wind, waves, or glaciers
ethanol	an alcohol fuel (ethyl alcohol) produced from fermenting sugars and starches found in plants
fission	splitting into parts; splitting or fragmenting the nucleus of atoms to release energy
fossil fuels	the remains of plants and animals that died hundereds of millions of years ago
fusion	the joining of nuclei of atoms to form heavier, more stable nuclei
gas	a state of matter in which the molecules are in random order and motion that takes on the shape of the available space; air is a mixture of gases
geologists	scientists who study the science that deals with the dynamics and physical history of Earth structures such as rocks, and the processes that cause change in the Earth
gigatons	a unit of measure equal to one billion tons
global warming	the increase of Earth's average atmospheric temperature
greenhouse gases	(GHGs) naturally occurring gases in the atmosphere that blanket the Earth keeping it warm
gross domestic product	the market value of goods and services from a nation in a specific year
hydrocarbon	an organic compound consisting of hydrogen and carbon
hydrosphere	all water on or around the Earth including surface, ground, ice, and water vapor
ice core	drilled sample from an ice sheet
impact	an impression or force one thing has on another
infrared radiation	electromagnetic waves produced from very hot objects, which are longer than visible light and shorter than radio waves and we can feel them produced from an incandescent bulb
intergovernmental	work that combines two or more levels of governments
kilowatt-hour	amount of energy it takes to burn a 100-watt light bulb for 10 hours
lithification	processes of compaction or cementation in which smaller sediments are forced together into rock or stone
lithosphere	the solid portion of the crust and upper mantle of the Earth
meteorologist	scientists who study the science dealing with the atmosphere and its phenomena, including weather and climate
methane	colorless, odorless, flammable gas used as fuel that is naturally released during decomposition of organic materials; consists of one carbon and four hydrogens—the major component of natural gas; it is a greenhouse gas; CH_4
Milankovitch Cycles	changes in the Earth's movements that affect climate
mitigation	relief; to lessen or make milder
nitrous oxide	also known as laughing gas, N_2O is a sweet-smelling and tasting, nonflammable, colorless gas
nonrenewable energy source	energy or natural resources that cannot be replaced once it has been used up
obliquity	the axial tilt of an object; difference between orbital and equatorial planes
oil embargo	an oil crisis imposed on the U.S. by countries who exported oil; took place in 1973 and 1974 and caused major price spikes and shortages in the U.S.
photosynthesis	process utilizing light as the energy source, in which green plants produce carbohydrates from carbon dioxide and water and release oxygen as a byproduct
polygeneration	combined heat, cooling, and power production at a plant
precession	the rotational motion of an axis (such as a wobbling top), caused by gravitational forces
precipitation	rain, snow, sleet, or hail that are products of condensation in the atmosphere that fall to Earth
radiation	the emitting of particles or waves giving off energy; energy from the sun in rays or waves

reforestation	the replanting of trees on deforested land
renewable energy source	energy or natural resources that are never used up or can be replaced
reservoir	a natural storage; an extra supply
respiration	inhaling and exhaling air; breathing
secondary energy source	requires the use of another energy source for production
smog	atmospheric emissions in fog
species	groups of organisms that have common properties or characteristics
sustainability	support; keep in existence or maintain
synfuel	synthetic fuel; a fuel in the form of a liquid or gas that is produced from the fermentation of substances like grains or from coal, shale, or tar sand
thermal expansion	the tendency of matter to change in volume due to a change in temperature
volcanism	relating to volcanic activity or volcanic force
weather	describes the meteorological conditions in the atmosphere over a short period of time
weathering	chemical and mechanical processes that decompose or break down rock

Exploring Climate Change Evaluation Form

State: ____________ **Grade Level:** ____________ **Number of Students:** ___________

1. Did you conduct the entire unit?	❑ Yes	❑ No
2. Were the instructions clear and easy to follow?	❑ Yes	❑ No
3. Did the activities meet your academic objectives?	❑ Yes	❑ No
4. Were the activities age appropriate?	❑ Yes	❑ No
5. Were the allotted times sufficient to conduct the activities?	❑ Yes	❑ No
6. Were the activities easy to use?	❑ Yes	❑ No
7. Was the preparation required acceptable for the activities?	❑ Yes	❑ No
8. Were the students interested and motivated?	❑ Yes	❑ No
9. Was the energy knowledge content age appropriate?	❑ Yes	❑ No
10. Would you teach this unit again?	❑ Yes	❑ No

Please explain any 'no' statement below.

How would you rate the unit overall?	❑ excellent	❑ good	❑ fair	❑ poor
How would your students rate the unit overall?	❑ excellent	❑ good	❑ fair	❑ poor

What would make the unit more useful to you?

Other Comments:

Please fax or mail to: **The NEED Project**
8408 Kao Circle
Manassas, VA 20110
FAX: 1-800-847-1820

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