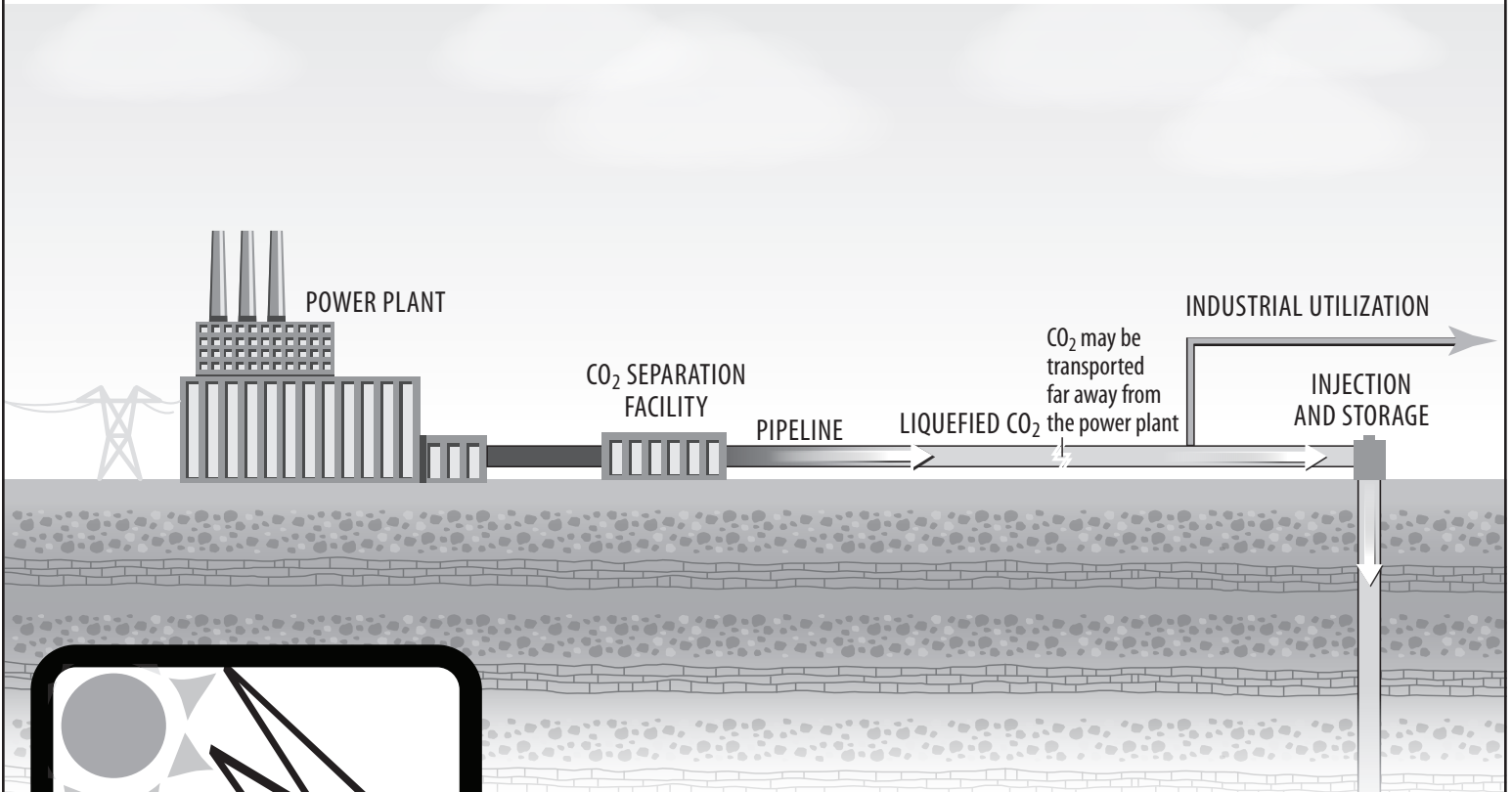


Carbon Capture, Utilization, and Storage






Informational text and hands-on explorations teach students about the properties of carbon dioxide and about developing technologies that allow carbon dioxide to be captured from stationary sources and utilized or stored in geologic formations.

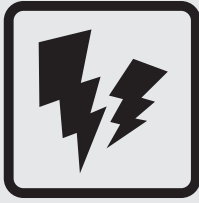


Grade Level:

Sec Secondary

Subject Areas:

-  Science
-  Social Studies
-  Language Arts
-  Math
-  Technology



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NEED Mission Statement

The mission of The NEED Project is to promote an energy conscious and educated society by creating effective networks of students, educators, business, government and community leaders to design and deliver objective, multi-sided energy education programs.

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In support of NEED, the national Teacher Advisory Board (TAB) is dedicated to developing and promoting standards-based energy curriculum and training.

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NEED believes in providing the most recently reported energy data available to our teachers and students. Most statistics and data are derived from the U.S. Energy Information Administration's Annual Energy Review that is published yearly. Working in partnership with EIA, NEED includes easy to understand data in our curriculum materials. To do further research, visit the EIA website at www.eia.gov. EIA's Energy Kids site has great lessons and activities for students at www.eia.gov/kids.



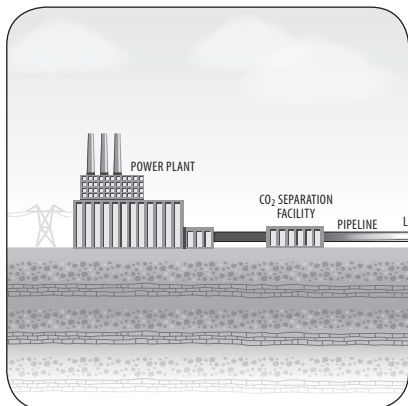
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Carbon Capture, Utilization, and Storage

As the United States and the global community work toward developing technologies and methods to mitigate the release of carbon dioxide, it is important for the public to understand the processes and technologies in place to do so. Carbon Capture, Utilization, and Storage (CCUS) is one advanced method for mitigating the release of carbon dioxide into the atmosphere from fossil-fueled power stations. The U.S. Department of Energy, the nation's utilities, and the engineering community are working together to find the best methods for CCUS. With this curriculum module, and other NEED activities, we hope to help students, teachers, and the local community understand why CCUS is part of the solution and how it will impact energy supply, demand, and cost. Teaching about CCUS in the classroom helps students understand the technologies, consider the future of careers in this industry, and makes them better energy consumers and decision makers.

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This guide was created with the support of the United States Energy Association, and the U.S. Department of Energy.



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.

The screenshot shows the NEED website interface. At the top left is the NEED logo (National Energy Education Development Project) and social media icons for Facebook, Twitter, Instagram, Pinterest, and LinkedIn. A search bar is located on the top right. A navigation menu includes: About NEED, Educators, Students, Partners, Youth Awards, Signature Programs, State Programs, and Contact. On the left side, there is a vertical menu with dropdown arrows for: Curriculum Resources, Professional Development, Evaluation, Supplemental Materials, and Curriculum Correlations. The main content area shows the breadcrumb path: Home > Educators > Curriculum Correlations. The title is "Curriculum Correlations". The text states: "NEED has correlated their materials to the Disciplinary Core Ideas of the Next Generation Science Standards. NEED has also correlated all of their materials to The Common Core State Standards for English/Language Arts and Mathematics. All materials have are also correlated to each state's individual science standards. Most files are in Excel format. NEED recommends downloading the file to your computer for use. Save resources, don't print!". Below this is a list of links:

- [Navigating the NGSS? We have What You NEED!](#)
- [NEED alignment to the Next Generation Science Standards](#)
- [Common Core State Standards for English and Language Arts](#)
- [Common Core Standards for Mathematics](#)
- [Alabama](#)
- [Alaska](#)



Carbon Capture, Utilization, and Storage Materials

ACTIVITY	MATERIALS NEEDED	
<i>Modeling Combustion</i>	<ul style="list-style-type: none"> ▪Molecular modeling kits 	
<i>Carbon Footprint</i>	<ul style="list-style-type: none"> ▪5 lb. Bag of charcoal briquettes ▪1 Tall, white kitchen trash bag ▪1 Plastic grocery bag ▪Paper towels ▪All purpose cleaning solution ▪White 8 ½" x 11" paper 	
<i>Properties of CO₂</i>	<ul style="list-style-type: none"> ▪Trash bags ▪5-10 Pounds of dry ice (keep in foam cooler until ready to use) ▪Work gloves ▪Tongs ▪Large, clear containers ▪Plastic trays ▪Bottle of bubbles 	<ul style="list-style-type: none"> ▪Bottles of water ▪Rubber balloons ▪Pipe cleaners ▪Tea light candles ▪Matches ▪8 oz. Plastic cups ▪Safety glasses
<i>Separating Mixtures</i>	<ul style="list-style-type: none"> ▪Salt ▪Sand ▪Gravel ▪Beakers ▪Water 	<ul style="list-style-type: none"> ▪Balances ▪Variety of filter materials that may include screens, cheesecloth, newspaper, etc. ▪Safety glasses
<i>Exploring Porosity</i>	<ul style="list-style-type: none"> ▪Small gravel ▪Medium gravel ▪Coarse or large gravel ▪100 mL Graduated cylinders ▪600 mL Beakers ▪Water ▪Food coloring ▪Safety glasses 	
<i>Enhanced Fuel Recovery Model</i>	<ul style="list-style-type: none"> ▪Clear glass jars with tight lids ▪Water ▪Marbles ▪Pebbles ▪Stones ▪Colored vegetable oil or lamp oil ▪Dry ice or effervescent tablets ▪Mason jars with lids ▪Pieces of 24" by ¼" tubing ▪Empty water bottles ▪Dark colored food dye ▪Drill ▪Safety glasses ▪Tongs ▪Silicon sealant ▪Tape ▪Tissue paper (optional) 	



Teacher Guide

Grade Level

▪ Secondary, grades 9-12

Time

6-10 Class periods

Web Resources

Bureau of Land Management

www.blm.gov

Energy Information Administration

www.eia.doe.gov

EIA Energy Kids

www.eia.doe.gov/kids

DOE Office of Fossil Energy

www.energy.gov/fe/office-fossil-energy

DOE Carbon Capture and Storage Research

www.energy.gov/fe/science-innovation/carbon-capture-and-storage-research

American Institute of Chemical Engineers, CCUS Information and Research

www.aiche.org/ccusnetwork/what-ccus

Evaluation

At the close of the unit, use the *Evaluation Form* on page 43 to evaluate the unit with your students.

Background

Carbon capture is a process designed to separate carbon dioxide (CO₂) out of the flue stream produced by coal, natural gas, and petroleum-fired power plants. By isolating the CO₂, it can be transported in liquid form to storage in deep geologic formations or, in some cases, utilized in enhanced oil or gas recovery, enhanced coal bed methane recovery, or calcification. The combined capture, storage, and utilization make up CCUS.

Science Notebooks

This curriculum references and refers students to use science notebooks. Experimental questions, procedures, sample data tables, and conclusion questions are provided on the worksheets. If you do not use science notebooks, students will need paper to allow space for hypotheses, additional observations, data analysis, and drawing conclusions. Or, you may make copies of the student worksheets as needed.

Introduction

Objectives

- Students will be able to define CCUS and explain its importance.
- Students will be able to describe carbon dioxide and identify its role in climate concerns.

Materials

- *Student Informational Text*, pages 17-28
- *Carbon Dioxide and CCUS KWL Chart*, page 29

Preparation

- Make a copy of the worksheet and text for each student.

Procedure

1. Ask students to fill out what they think they know, and questions they currently have, about carbon dioxide. Ask students to identify what they think CCUS is and list it on their KWL chart.
2. Have students read the informational text and keep track of questions and new pieces of information they've learned through their reading.
3. Discuss the information with the class, and let students share what they learned.

Activity 1: Modeling Combustion

Objectives

- Students will be able to draw the molecular structure of carbon dioxide.
- Students will be able to correctly write a chemical formula for the combustion of fossil fuels.

Materials FOR EACH GROUP

- Molecular modeling kit
- *Modeling Combustion* worksheet, page 30

Note

If molecular modeling kits are not accessible, toothpicks and spherical objects of different colors and/or sizes can be a suitable substitute.

Preparation

- Make a copy of the worksheet for each student.

Procedure

1. Review with students that energy in fossil fuels is stored in the form of hydrocarbons. A hydrocarbon is a compound containing only carbon and hydrogen atoms. Methane (CH₄) is the simplest hydrocarbon molecule made of four hydrogen atoms and one carbon atom.
2. Ask students how energy is released from hydrocarbons. (We burn them.) Combustion requires a fuel source, oxygen, and heat.
3. Give students the *Modeling Combustion* worksheet. Let students work in groups to model hydrogen, oxygen, methane, and the products of combustion.

Combustion Formula



Activity 2: Carbon Footprint

Objective

- Students will develop an understanding of individual carbon footprints.

Materials

- 5 lb. Bag of charcoal briquettes
- 1 Tall, white kitchen trash bag
- 1 Plastic grocery bag
- Paper towels
- All purpose cleaning solution
- 1 Sheet white 8 ½" x 11" paper per student
- *Carbon Footprint* worksheet, page 31

Preparation

- Prior to the start of the activity, have students research uses for CO₂ as homework. Encourage students to find ways CO₂ is used in residential, industry, and medical settings. Students should make a list and bring the list with them to class.
- Gather the materials and cover the table where you will do the demonstration with the white trash bag.

Procedure

1. Break students into small groups to brainstorm a list of uses for CO₂ based on their findings from the homework assignment.
2. Based on the first activity, students should understand that CO₂ is released into the atmosphere during fossil fuel combustion. This includes combustion from fossil fuel power plants generating electricity, from manufacturing processes, and from the burning of fossil fuels in vehicles.
3. Explain that CO₂ is usually found in its gaseous state. It is colorless and transparent. Even though we know CO₂ 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, so the briquettes will represent the amount of CO₂ or carbon in one gallon of gas. The average gallon of gasoline contains about five pounds of carbon. There are about 100 briquettes in the bag. By dividing five pounds of carbon by 100 briquettes, that means one briquette represents about 0.05 pounds of carbon.
4. Pass out the *Carbon Footprint* worksheet. Work through the sample problems as a class. Then, have students complete the rest of the worksheet individually, calculating their transportation carbon footprint. *Note: If students do not know the fuel economy of their vehicles, use the website, www.fueleconomy.gov.*
5. When students are done calculating their transportation carbon footprint, give them a separate piece of paper. Have students trace an outline of their shoe. Inside the footprint, have students write at least three suggestions for reducing their carbon footprint. Students should also reflect on why it is important to understand their carbon footprint and why it matters.

Extension

- Students can calculate their families' household emissions using the Environmental Protection Agency's Emissions Calculator at <http://www3.epa.gov/carbon-footprint-calendar>. It will be most accurate if students have an energy bill from home they can reference.

Activity 3: Properties of CO₂

Objective

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

Materials FOR EACH GROUP

- | | |
|---|---|
| ▪ Trash Bag | ▪ Pipe cleaner |
| ▪ Dry ice "cube" or chunk
(keep in foam cooler until ready to use) | ▪ Tea light candle |
| ▪ Work gloves | ▪ Matches |
| ▪ Tongs | ▪ 8 oz. Plastic cup |
| ▪ Large, clear container | ▪ Safety glasses |
| ▪ Plastic tray | ▪ <i>Properties of CO₂</i> worksheet, page 32 (for everyone) |
| ▪ Bottle of bubbles | ▪ <i>Dry Ice Safety</i> , page 15 |
| ▪ Bottle of water | |
| ▪ Balloon | |

Preparation

- Cover work surfaces with plastic trash bags or table coverings.
- Prepare a copy of *Dry Ice Safety* to project for the class. Review the safety recommendations before handling any dry ice.
- Make a copy of the worksheet for each student.
- 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. Each group will need a piece of dry ice about the size of a large ice cube.

Procedure

1. Project and discuss with the class the safety instructions for working with dry ice.
2. Place some dry ice on a plastic tray, place the tray of dry ice in the large, clear container.
3. Explain that carbon dioxide (CO₂) is usually found in its gaseous state. However, it also can be found in a solid form or a liquid form. Dry ice is frozen CO₂; it is CO₂ 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 CO₂ warms up?" Have students record their predictions in a science notebook or on the worksheet. Have students observe the dry ice in the container for a few minutes. Students should record observations using pictures and words in their science notebooks or on the worksheet. Ask students to explain what they are seeing. Discuss why CO₂ does not exist as a liquid at atmospheric pressure. As solid CO₂ thaws it transforms directly into a gas, or sublimates. CO₂ exists as a liquid only under great pressure.
5. Pour water onto the dry ice to produce enough CO₂ gas to fill the container.
6. Blow bubbles into the container. Have students record their observations and explain what is happening. After students have had time to write down their own thoughts, explain how CO₂ is denser than air. Since the bubbles are filled with air, they float on top of the CO₂ gas collected in the container.
7. Light a tea candle. Using the plastic cup, collect some CO₂ gas and pour it over the candle. Students should record what happens and explain what they saw. Explain how CO₂ displaces less dense oxygen. The CO₂ is denser than air and pushes the oxygen away. The fire needs oxygen to continue burning so the fire is extinguished. This is why CO₂ is used in fire extinguishers.
8. 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. Students should record observations and explain what happened.

Activity 4: Separating Mixtures

Background

In this inquiry-driven activity, students will use physical properties to simulate the separation of gases in the flue stream of a power plant. In this simulation, a mixture of salt, sand, and gravel is used to represent mixed gases after combustion. Provide your students various sizes of beakers and types of filter materials and allow them to design their own experiment to separate the mixture.

Objective

- Students will be able to use physical properties to separate mixtures into individual parts.

Materials *FOR EACH GROUP*

- Salt/sand/gravel mixture
- Water
- Beakers (various sizes)
- Balance
- A variety of filter materials that may include screens, cheesecloth, newspaper, etc.
- Safety glasses
- *Separating Mixtures* worksheet, page 33

Preparation

- Create a mixture of salt, sand, and gravel so that each group in your classroom will receive approximately 100 g of material. About 40 g should be sand.
- Make a copy of the worksheet for each student.

Procedure

1. Review the properties of carbon dioxide that students observed in the previous investigation. Explain how scientists use the physical and chemical properties of CO₂ to separate it from other gases (nitrogen, water vapor, carbon monoxide, nitrogen oxides, and sulfur oxides) in a power plant's flue stream.
2. In the previous investigation students observed how carbon dioxide is more dense than air. It is also more dense than nitrogen or pure oxygen. It is less dense than sulfur dioxide. Other physical properties of CO₂ include:
 - Relative to other gases (sulfur dioxide, oxygen, nitrogen, nitrous oxide) carbon dioxide has a higher melting point, it will become a solid at -78 degrees Celsius at standard pressure (water vapor freezes at zero).
 - Carbon dioxide will not form a liquid at standard pressure such as other gases will do. (For example, water vapor can become liquid water.) It will deposit from a gas to a solid instantly when it reaches its freezing point.
3. Divide the class into small groups. Give each group 100 g of the salt/sand/gravel mixture. Tell students that the mixture represents the gases found in the flue stream of a fossil fuel power plant. Carbon dioxide is represented by the sand. Show students the various items you have available for separating mixtures. Students will need to develop a technique to separate the sand from the other components of the mixture using the physical properties of the materials.
4. After students have separated out the sand, inform the group how much sand was originally in their mixture. Students should weigh the sand and calculate their recovery of the sand and compare it to the known amount. If students have used water they will need to let the sand dry before they complete the calculation.
5. After students have finished the activity, discuss as a class what methods were used to isolate the sand and how successful their methods were. Do students feel confident that they separated out all of the sand? Why or why not?

Extension

- Provide students with additional combinations of materials, such as iron filings, salt, and sand, to explore other physical properties used to separate out mixtures.

Activity 5: Exploring Porosity

Objective

- Students will be able to explain how porosity influences a material's ability to store carbon dioxide.

Materials FOR EACH GROUP

- 350 cm³ Small gravel
- 350 cm³ Medium gravel
- 350 cm³ Large gravel
- 100 mL Graduated cylinder
- 3 – 600 mL Beakers
- Water
- Food coloring
- Safety glasses
- *Exploring Porosity* worksheet, page 34

Preparation

- Gather materials and separate the proper amounts of each size gravel for students.
- If desired, dye the water students will use ahead of time. It needs to be dark enough that it is easily visible to students, however the activity can be done without food coloring, if necessary.
- Make a copy of the worksheet for each student.

Procedure

1. Review with students that porosity is the measure of the amount pores, or tiny openings, between grains in rock or sediment. Permeability describes how well a rock or sediment allows a fluid to pass through its pores.
2. Divide the class into groups of three to four students.
3. Pass out the *Exploring Porosity* worksheet and review the procedure with the class.
4. After students have completed the investigation, compare and discuss the results.

Activity 6: Enhanced Fuel Recovery Model *OPTION A: DRY ICE AND OPTION B: EFFERVESCENT TABLETS*

Objective

- Students will model how carbon dioxide can be used to retrieve additional oil from a reservoir.

Materials

FOR DEMONSTRATION

- Clear glass jar with tight lid
- Water
- Marbles
- Pebbles
- Stones
- 150 mL Colored vegetable oil or lamp oil

OPTION A: FOR EACH SMALL GROUP

- 2 Mason jars with lids
- 2 Pieces of 24" by ¼" tubing
- 150 mL Vegetable oil or lamp oil
- 350 mL Water
- 1 Empty water bottle
- 1 Dark colored food dye
- 1 Piece of dry ice, about the size of an ice cube
- Assorted rocks, sand, and marbles
- Drill
- Tongs
- Silicon sealant
- Safety glasses
- Tape
- Enhanced Fuel Recovery Model* worksheets, page 35-36
- North American Oil and Gas Reservoirs* map, page 16

OPTION B: FOR EACH SMALL GROUP

- 2 Mason jars with lids
- 2 Pieces of 24" by ¼" tubing
- 150 mL Vegetable oil or lamp oil
- 350 mL Water
- 1 Empty water bottle
- 1 Dark colored food dye
- 6 Effervescent tablets
- Assorted rocks, sand, and marbles
- Drill
- Tongs
- Silicon sealant
- Safety glasses
- Piece of tissue paper
- Tape
- Enhanced Fuel Recovery Model* worksheets, page 37-38
- North American Oil and Gas Reservoirs* map, page 16

Preparation *FOR THE DEMONSTRATION*

- Fill the jar with marbles, stones, and pebbles.
- Add 150 mL of vegetable oil or lamp oil. This represents crude oil.
- Fill the rest of the jar with water.
- Put the lid on and secure tightly.

Preparation *FOR THE STUDENT LAB*

- Prepare a copy of the map of *North American Oil and Gas Reservoirs* to project for the class.
- Drill ¼" holes in the lids to the mason jars. Each small group will need one jar with two holes in the lid, and one jar with one hole in the lid.
- Choose option A or B to complete the activity. Option A calls for a piece of dry ice to generate CO₂ to force liquids from the reservoir containing the sand, pebbles, marbles, water, and oil. If dry ice is not available, effervescent tablets can be substituted in option B. Choose option A or B to complete the activity based on your preference and access to the materials.
- Make a copy of the worksheets for the correct option, so each student has a copy.

Procedure

- Show the class the demonstration jar you have made. Tell the students that this is a model of an oil reservoir, magnified many times over. Oil (the colored oil) is trapped within the pore space of rocks.
- Gently shake the jar and show students how the oil is trapped in among the rocks. Pass the jar around and direct the class to the map of *North American Oil and Gas Reservoirs* to show where oil may be trapped.
- Review Steps 3 and 4: Utilization and Geologic Storage in the *Student Informational Text*. Explain to students that they are going to build their own model of an enhanced fuel recovery system like those used for oil recovery at a reservoir.



CONTINUED ON NEXT PAGE

CONTINUED FROM PREVIOUS PAGE

4. Divide students into small groups. Pass out the *Enhanced Fuel Recovery Model* worksheets and go over the assignment. Remind students of the safety rules for handling dry ice, if necessary. Circulate around the room and assist students as needed.

NOTE: This is a model of the enhanced fuel recovery process. Students are using CO₂ in a gas form to pump out the oil in their model reservoir. In actual practice, CO₂ is pressurized and injected into the reservoir as a liquid. Geologic pressure keeps the CO₂ in liquid form. Other enhanced fuel recovery models are being tested but are not used in practice.

Extension

▪ Ask students to redesign the experiment to retrieve the oil using different materials to optimize recovery.

Activity 7: Researching Regional Sequestration Partnerships

Objective

▪ Students will be able to describe current CCUS projects and technologies in North America.

Materials

- Computer and internet access
- Copies of *Research Regional Sequestration Partnership*, pages 39-40

Preparation

- Familiarize yourself with the Carbon Sequestration Regional Partnerships at <http://energy.gov/fc/science-innovation/carbon-capture-and-storage-research>.
- Make a copy of the worksheets for each student.

Procedure

1. Divide the class into seven small groups. Assign each group to a different regional partnership and pass out the worksheets.
2. Each group should look at the projects underway in their assigned regional partnership. The group should choose a project to research and will create a multimedia presentation about the project.
3. In their presentations, groups should answer the following:
 - What partnership are you assigned to? What states/provinces does it encompass?
 - What project are you highlighting? What is the location?
 - How long has the project been operating?
 - What is the CO₂ source?
 - How is the CO₂ being captured?
 - How is the CO₂ being utilized?
 - How is the CO₂ being stored?
 - How much CO₂ has been stored?
 - What lessons have been learned from this project?
 - What is the next phase of the project?
4. Have students present their multimedia projects to the class. As presentations are made, the other students should take notes.

Writing Extension

▪ Ask each student to pick a project different from the one they originally researched and write a compare and contrast paper.



Internet Resources

General CCUS Resources

CCS 101

www.CCS101.ca

FutureGen Alliance

<http://www.futuregenalliance.org>

National Energy Technology Laboratory

www.netl.doe.gov

U.S. Carbon Sequestration Council's Education Papers

www.uscsc.org/educational_papers.asp

U.S. Department of Energy

www.energy.gov

U.S. Department of Energy, Office of Fossil Energy

www.energy.gov/fe/office-fossil/energy

U.S. Energy Association

<http://usea.org>

U.S. Environmental Protection Agency

www.epa.gov

U.S. Geological Survey

www.usgs.gov

Regional Sequestration Partnerships

Big Sky Carbon Sequestration Partnership

www.bigskyco2.org/

Midwest Geological Sequestration Consortium

www.sequestration.org/

Midwest Regional Carbon Sequestration Partnership

www.mrcsp.org

Plains CO₂ Reduction Partnership

www.undeerc.org/pcor/

Southeast Regional Carbon Sequestration Partnership

www.secarbon.org/

Southwest Partnership

www.southwestcarbonpartnership.org/

West Coast Regional Carbon Sequestration Partnership

www.westcarb.org/



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 or -78.3°C ! It melts 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 should 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 melts 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 almost immediately. 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. 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 goggles 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 pant or have difficulty catching your breath. This is a sign that you have breathed 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.

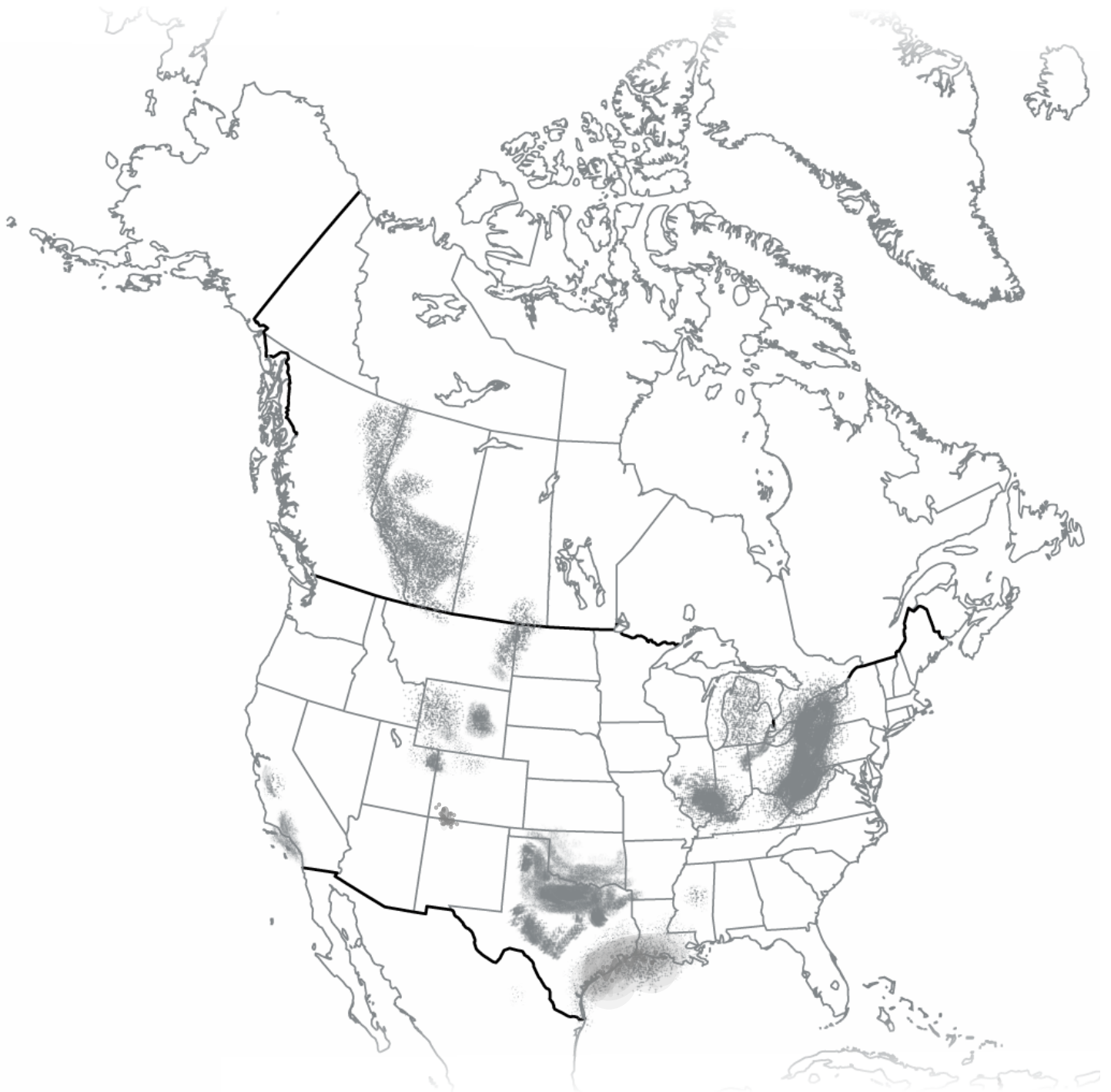


Disposing of Dry Ice

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.



North American Oil and Gas Reservoirs





Carbon Capture, Utilization, and Storage

Student Informational Text

Introduction

Most people in the United States use electricity on a daily basis. Electricity is not a primary source of energy because it has to be created. Rather, electricity is a secondary source of energy, or an **energy carrier**. We generate electricity from **fossil fuels** (coal, natural gas, oil), nuclear fuel, and renewable energy resources (hydropower, biomass, solar, wind, and geothermal). All of these resources are needed to meet our electricity demand.

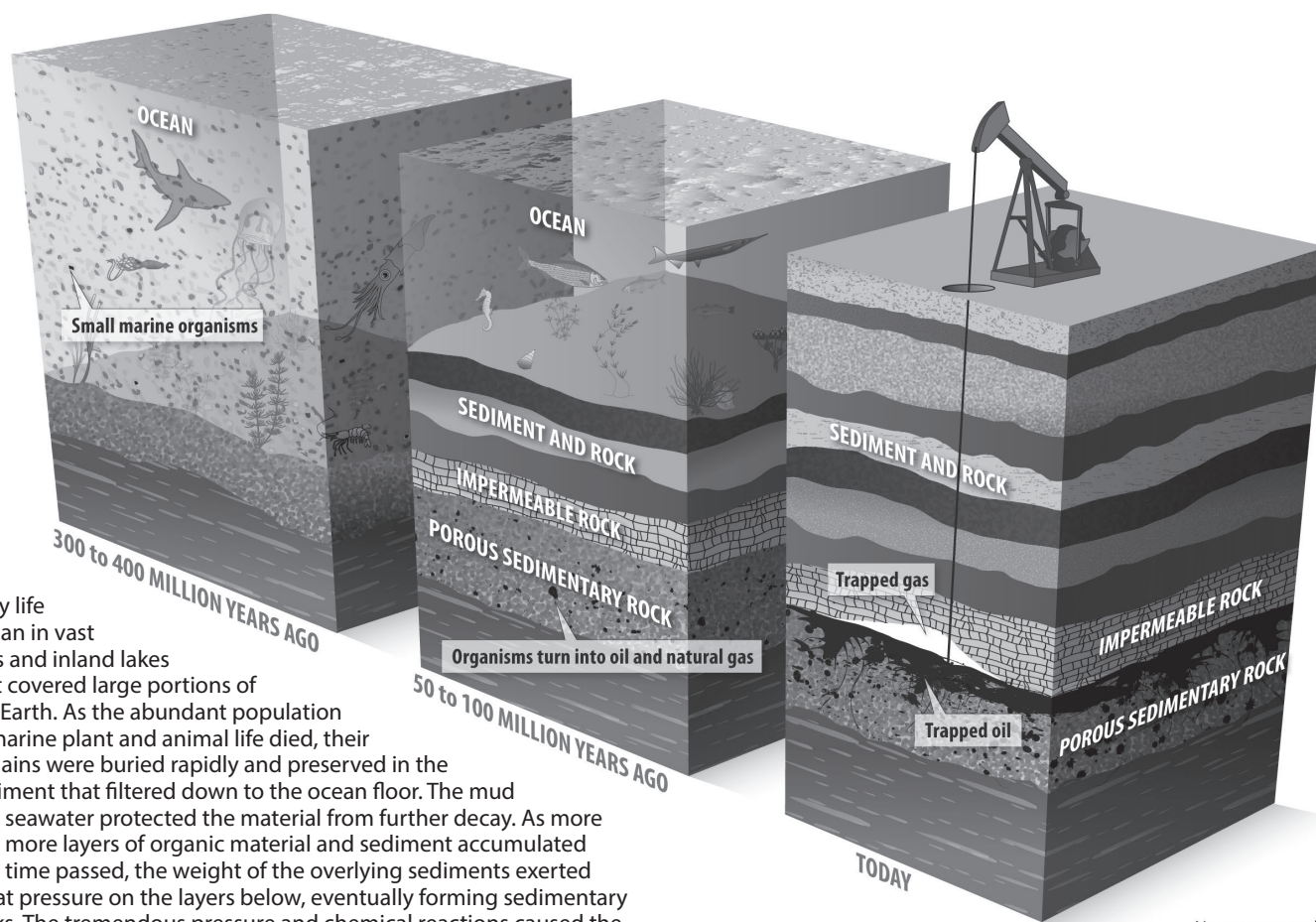
Fossil fuels are the sources behind about 68 percent of electricity generated in the United States. While fossil fuels provide affordable and reliable energy, there is growing concern about the relationship between **carbon dioxide** emissions produced at fossil fuel power plants and global **climate change**. Scientists have developed

new technologies and processes that allow for the capture and storage of carbon dioxide (CO₂). These technological advances will stabilize and reduce the amount of CO₂ **emissions**, allowing for the continued use of domestic fossil fuel resources to meet our energy demand.

Early Uses of Fossil Fuels

Humans have been using **coal** and **petroleum** for thousands of years. Ancient Egyptians gathered crude oil that had seeped to the surface as a medicine for wounds, and oil in lamps to provide light. Native Americans skimmed oil off the surface of lakes and streams to use as medicine and to water-proof canoes. The Chinese were the first to use coal found at or near land surfaces to smelt copper

Origins of Fossil Fuels



Early life began in vast seas and inland lakes that covered large portions of the Earth. As the abundant population of marine plant and animal life died, their remains were buried rapidly and preserved in the sediment that filtered down to the ocean floor. The mud and seawater protected the material from further decay. As more and more layers of organic material and sediment accumulated and time passed, the weight of the overlying sediments exerted great pressure on the layers below, eventually forming sedimentary rocks. The tremendous pressure and chemical reactions caused the formation of coal, crude oil, and natural gas.

Today, natural gas and oil remain trapped in the folds of rock layers around the world.

Note: not to scale

over 3,000 years ago. In the second century, Romans in Britain were using coal to heat public and private baths. The Aztecs used coal as a heat source for cooking, and for ornaments. Hopi Indians used coal to bake pottery made from clay.

However, it was not until the Industrial Revolution that we began using these sources in large quantities. Engineers had invented new tools and machines that made accessing and using the energy in fossil fuels much easier. Thomas Edison's invention of a long lasting incandescent light bulb also opened a new market for the use of fossil fuels—electric power generating stations.

Electricity

Electricity has greatly improved our quality of life over the last 100 years. Because of electricity, we easily have light at any hour. We are healthier because food is preserved through refrigeration and freezing. We can also maintain comfortable temperatures in our homes, schools, and work places in any season. We are entertained by television and movies, and we are able to keep our cell phones and tablet batteries charged. People are even starting to use electricity to power their vehicles.

While plugging in an appliance or flipping a light switch makes it easy for us to use electricity, it is not easy to produce electricity. There is a tremendous amount of work and energy involved in generating electricity and moving electricity from the power plant to your home and school.

Generating Electricity

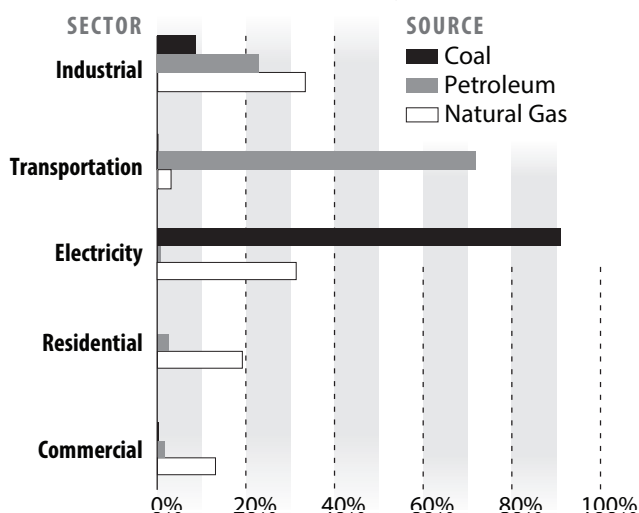
Almost all electricity produced in the United States is generated by large, central power plants. Coal and **natural gas** plants are common because there is a plentiful domestic supply of these sources. In fact, the United States has the largest recoverable **reserves** of coal in the world. The fuel is relatively inexpensive, and the plants are less expensive to build compared to other power plants. Fossil fuel plants that use coal and natural gas are important sources for meeting the electricity demand in the United States.

Coal power plants are **baseload** power plants. This means that they supply electricity 24 hours a day, seven days a week, usually at a constant rate. The only time these plants do not operate is when they must be taken off-line for maintenance. Bringing a coal power plant off-line takes time, and when it goes back on-line it requires time to build up to its full generating capacity. For the most part, coal power plants are producing a constant amount of electricity and sending it out onto the **electric grid**.

Natural gas power plants are commonly used as baseload plants and as peak demand plants. During certain times of the day (from after school until after dinner), and certain periods of the year (hot summer days), there is a larger demand for electricity. This is referred to as peak demand. Baseload power cannot meet the demand, so peak load power plants are brought on-line. Natural gas plants are good peaking facilities because they can easily be turned on to help meet the electricity demands and turned off when they are not needed.

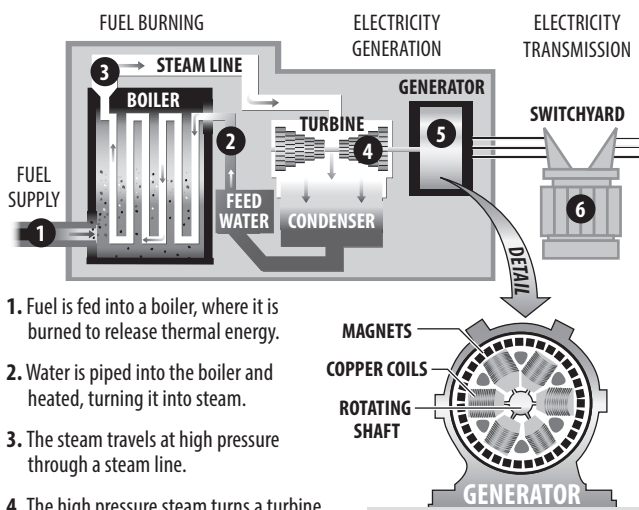
Coal and natural gas are both used as fuel in thermal power plants. The fuel is fed into a furnace where it is burned to release thermal energy. The released thermal energy superheats pure water changing it into steam in a boiler. The very high pressure steam (75 to 100 times normal atmospheric pressure) is piped to a turbine

Fossil Fuel Consumption By Sector, 2013



Data: Energy Information Administration

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.

where it spins the blades of the turbine. The blades are connected to a shaft, which is a part of the generator. Inside the generator, the rotating shaft has coils of copper wire connected to it. The shaft and coils of wire are surrounded by large, strong magnets. The shaft spins the copper coils rapidly through the magnetic field of the magnets. This induces a current inside the copper coils of wire. Electrons move through the wire to a transformer, which steps up the voltage to send the electricity onto the electric grid.

The steam does not stop once it reaches the turbine blades. From the turbine blades it continues traveling through pipes to a condenser where it is cooled into liquid water by passing it through pipes circulating over a large body of water or cooling towers. The water then returns to the boiler to be used again.

Atmospheric Impacts

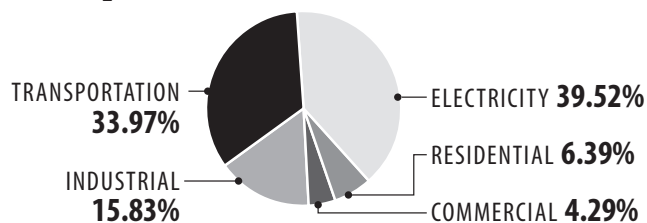
There are many advantages and societal benefits of burning relatively cheap coal and natural gas for electricity, heating and cooling, and even transportation. However, there are also environmental impacts associated with burning fossil fuels, including the release of emissions through **flue gas**. Nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon dioxide (CO₂), particulate matter (PM), and water vapor are all products of fossil fuel **combustion**. Regulations require power plants to reduce NO_x, SO₂, and PM through the use of scrubbers and flue gas desulfurization.

Naturally found in the atmosphere, CO₂ itself is not considered a pollutant. The CO₂ being released from burning fossil fuels was part of the atmosphere millions of years ago before being captured by plants and sea organisms. Carbon atoms naturally cycle through living organisms, the atmosphere, the oceans, and the Earth's crust through a process known as the **carbon cycle**. In the carbon cycle, carbon is exchanged at differing rates among different reservoirs. Fossil fuels, like coal and natural gas for example, act as a **carbon sink** for **absorption** of carbon as it is released from different parts of the cycle. Burning these fossil fuels, however, adds carbon to the atmosphere faster than it can be removed naturally. The balance of the flows or exchanges between sources of carbon (emissions, respiration) and sinks (fossil fuels, sediments, ocean), is referred to as the **carbon budget** or carbon flux. There has been a concern about the buildup of CO₂ concentrations in the atmosphere. CO₂ is a **greenhouse gas**, which helps to trap heat in the atmosphere through the **greenhouse effect**. International scientific consensus has concluded that the increase of CO₂ in the atmosphere is one of the causes of global climate change.

Carbon Capture, Utilization, and Storage

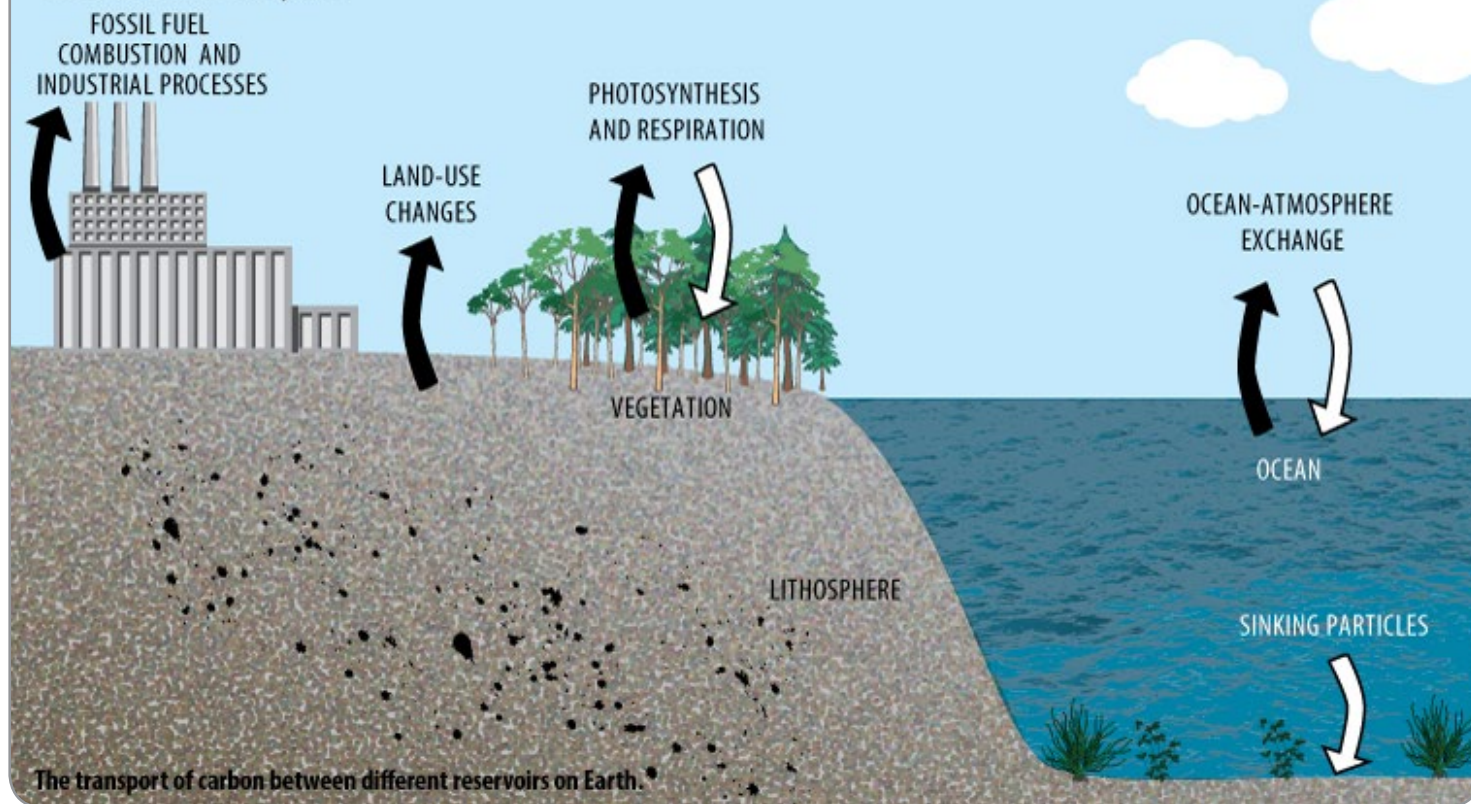
In 2012, over 32.7 billion **metric tons** of CO₂ were emitted worldwide related to fossil fuel energy consumption. Increasing levels of CO₂ is not an issue for just the United States, it is a global issue. Research and developmental projects are now underway around the world to find affordable and sustainable ways to capture CO₂ before it enters the atmosphere, then to use it, and/or store it deep underground where it cannot escape. The term used to describe this process is **Carbon Capture, Utilization, and Storage** (also known as carbon sequestration), or CCUS. The goal of CCUS is to mitigate the levels of CO₂ entering the atmosphere.

U.S. CO₂ Emissions By Sector, 2013



Data: Energy Information Administration

Global Carbon Cycle



While the transportation sector is responsible for about one-third of the country's CO₂ emissions, scientists believe the best use of CCUS technologies will be to focus on large stationary sources of CO₂ emissions. Capturing emissions from individual mobile sources would be very challenging. Mitigating the transportation sector's role in climate change is happening in other ways including efficiency measures, fuel switching, and **terrestrial sequestration**. Electric power plants and large industrial plants, such as cement factories, oil refineries, and steel works, are stationary sources identified as potential sources to use CCUS technologies.

Four Main Parts to a CCUS System

1. The CO₂ gas is captured before or after fossil fuels are burned and compressed into a liquid form.
2. The liquid CO₂ is transported via pipeline to a utilization or geologic storage site.
3. At the utilization site, CO₂ is transformed into usable materials. Sometimes the utilization site is also the storage site.
4. At the storage site, the CO₂ is injected deep into the subsurface of the Earth where it is safely stored and monitored.

All parts of the CCUS system—CO₂ capture, transport, utilization, and storage—are currently done on a small scale. If CCUS can be used on a large scale, there is potential for CCUS to capture and store up to 90 percent of the CO₂ emitted into the atmosphere from stationary fossil fuel plants.

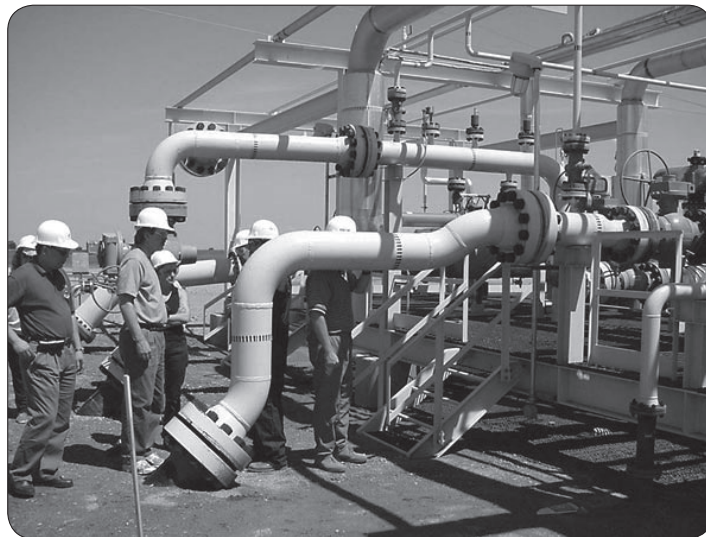
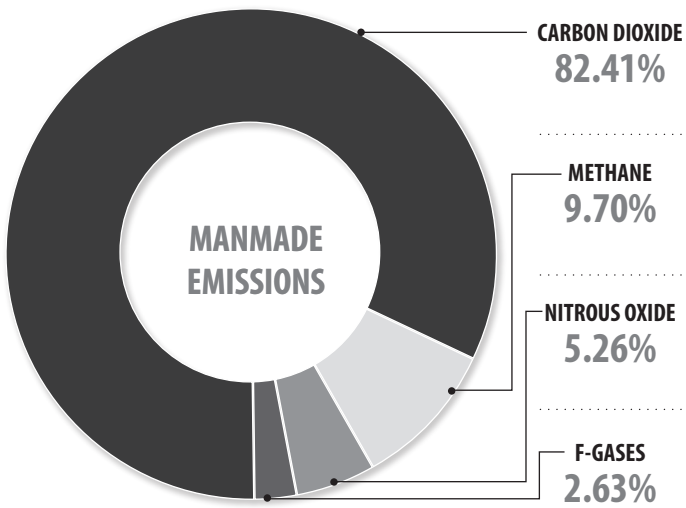


Image courtesy of Petroleum Technology Research Centre

This pipeline at Cenovus' oil field in Weyburn, Saskatchewan, Canada, has transported CO₂ 330 km from Beulah, ND. The CO₂ will be used for enhanced oil recovery, and ultimately stored underground in the depleted oil reservoir.

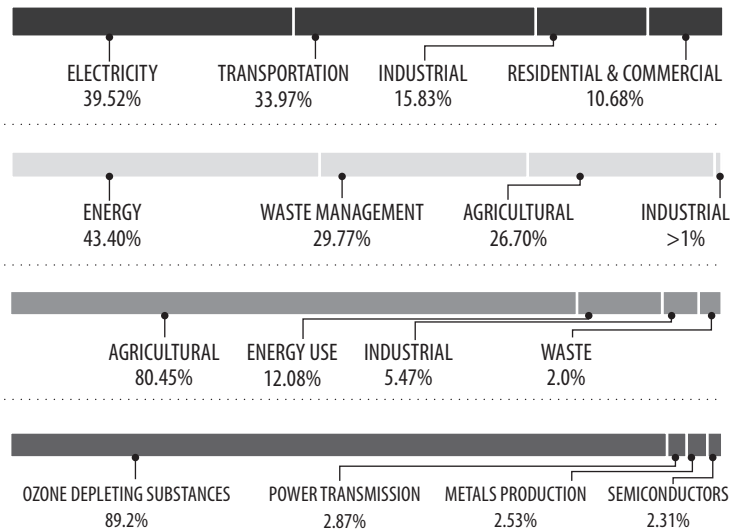
U.S. GREENHOUSE GAS EMISSIONS, 2013



Data: U.S. Environmental Protection Agency

*F-gases include HCFCs, PFCs, and SF₆, which are used in many different industrial applications, including refrigerants, propellants, and tracer chemicals.

SOURCES



▪ Step One: CO₂ Capture

There are a number of different CO₂ capture technologies available or currently being tested. It is likely that a hybrid of capture techniques will be used depending on the fuel source, and whether a plant is being retro-fitted with capture technology, or if it is a new plant with capture technologies built in.

POST-COMBUSTION CAPTURE

In the post-combustion capture method, the power plant front-end operations remain unchanged. Fuel is fed into a furnace where it heats water to steam. In a conventional fossil fuel plant, fuel combusts in the presence of air that is 21 percent oxygen and 78 percent nitrogen. The remaining one percent is a combination of eight gases including carbon dioxide, argon, methane, and helium. When oxygen and fuel are combined, the main products formed are CO₂ and H₂O. The gas created by the burning of fossil fuels in a power plant is called flue gas. The majority of flue gas is atmospheric nitrogen and water vapor, with CO₂ making up only 4-15 percent of the end product.

Before entering the atmosphere, flue gas is treated by scrubber and flue gas desulfurization technologies, which remove impurities regulated by the Environmental Protection Agency. In post-combustion capture, the flue gas would continue on, passing through a vessel containing a chemical solution such as aqueous amines (nitrogen containing organic compounds) or chilled ammonia (NH₃). The CO₂ bonds with the chemicals creating a concentrated CO₂ solution. The solution is then heated to release the CO₂, and the absorbing chemicals are recycled back to the beginning of the process.

A benefit of this capture technique is that it has been used in other industries, such as natural gas and refinery treatment plants, and utilizes well understood technologies within the current context. The natural gas industry is using this technology already. The food and beverage industry uses this method to provide CO₂ for liquid and food preservation. Fertilizer manufacturing uses CO₂ as a feedstock. The construction industry uses CO₂ for concrete manufacturing.

Because there is a large financial investment in electricity generation from coal and other fossil fuels, it is important to find solutions that preserve these investments as well as take advantage of an abundant, inexpensive, domestic fuel source.

The world's first commercial, post-combustion, coal-fired carbon capture project to be used for more than testing came online in the fall of 2014. The Boundary Dam CCS Project in Saskatchewan, Canada, repurposed a coal-fired generation unit to include carbon capture technology. This low-emission power generation facility generates 120 megawatts of electricity and reduces CO₂ by 1 million tonnes per year. Captured CO₂ is piped to oil fields nearby for use in enhanced oil recovery, or stored in an Aquistore well deep underground.

What is Carbon Capture, Utilization, and Storage?

CCUS is a process for reducing greenhouse gas emissions into the atmosphere by capturing CO₂ from stationary sources and using the CO₂ in new applications or storing the CO₂ in underground storage sites.

Post-Combustion Capture

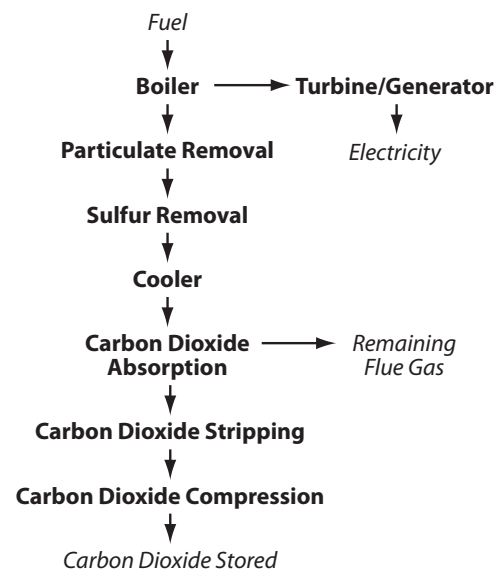
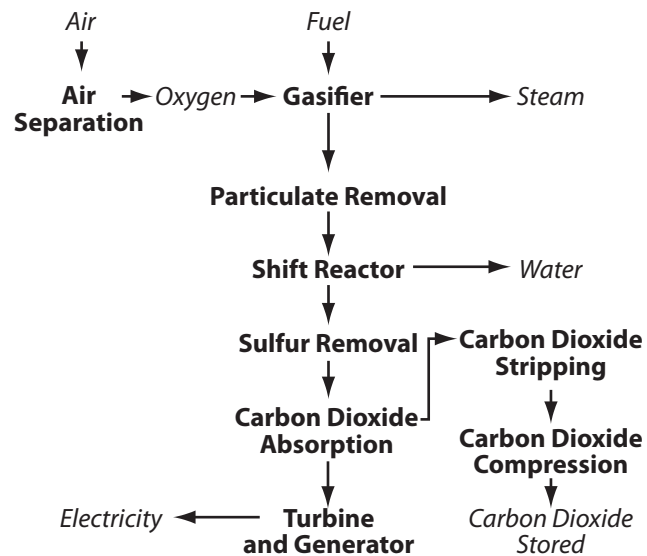


Image courtesy of Southeast Regional Carbon Sequestration Partnership

The photo above shows the CO₂ capture unit at Alabama Power's Plant Barry, the largest carbon capture facility in the U.S. Using a post-combustion capture process developed by Mitsubishi Heavy Industries, CO₂ will be captured and then transported through 12 miles of pipeline to the injection site called the Paluxy Formation.

The Gulf Coast region contains the largest capacity saline sinks in the United States. The Southeast Regional Carbon Sequestration Partnership is testing CO₂ injection and storage into the Paluxy Formation. Injection of CO₂ began in 2012. Approximately 100,000 to 150,000 tonnes of CO₂ will be injected each year for up to three years. In the first ten days of injection, more than 2,000 tonnes CO₂ had been injected and monitored.

Pre-Combustion Capture

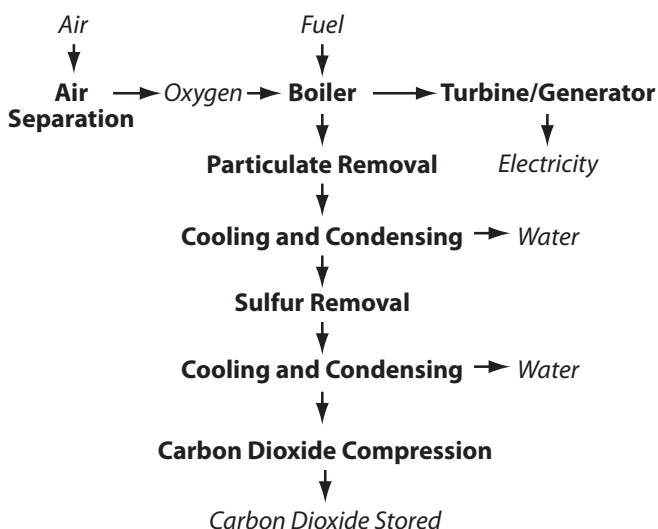


PRE-COMBUSTION CAPTURE

Capturing CO₂ with pre-combustion methods also uses existing technology. Prior to being burned, the fuel is combined with oxygen and steam to divide the fuel into carbon monoxide (CO), CO₂, and hydrogen. When coal is the fuel source, a process called **coal gasification** converts the coal into a cleaner burning synthetic gas, or **syngas**, that consists of carbon monoxide and hydrogen. The syngas can be reacted a second time with steam producing a mix of CO₂ and hydrogen. This creates a CO₂ concentration around 35-45 percent, which makes capturing the CO₂ easier than in other methods. The hydrogen goes on to be used as the fuel to generate electricity. Burning hydrogen produces thermal energy and water vapor, producing emission free electricity.

While pre-combustion capture is being used by the fertilizer industry, natural gas reforming, and applied to chemical and refining industries, it is not widely used by the electricity industry. The initial fuel conversion process is costly, and without stronger clean air requirements many facilities find it is not yet worth the cost. Pre-combustion will be most cost effective in new power facilities with higher efficiencies and integrated capture technologies.

Oxy-Fuel Combustion Capture



OXY-FUEL COMBUSTION CAPTURE

Rather than using air for combustion, researchers are looking at using pure oxygen. Burning fossil fuels with pure oxygen produces an exhaust composed only of concentrated CO₂ and water vapor. Concentrations of CO₂ could be greater than 80 percent and much easier to separate.

Oxy-fuel technology is still in developmental stages in the electric power sector. Extracting oxygen from air is expensive and this process itself consumes energy. Another challenge is that in conventional, pulverized coal plants, combustion occurs at temperatures from 1,300-1,700 degrees Celsius (2,300-3,000° Fahrenheit). Pure oxygen combustion occurs at much higher temperatures, around 3,500°C (6,332°F). This temperature is too high for typical power plant materials to withstand. In the future, this may prove to be a good option for retrofitting existing power plants.

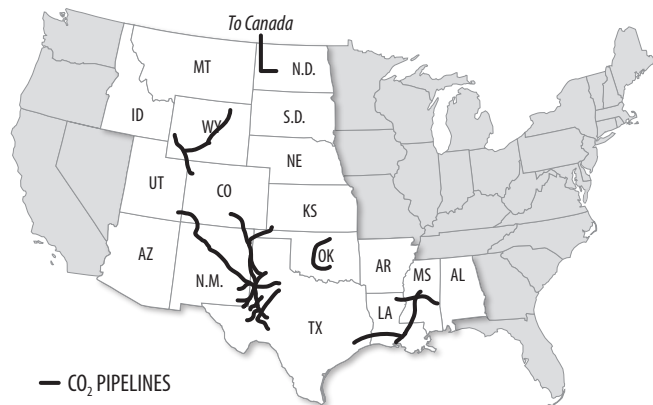
▪ Step Two: CO₂ Transport

Once CO₂ is captured, it must be transported to a storage site. In most cases, CO₂ will not be stored on power plant property. Instead, it will be compressed into a liquid and transported to locations where the geology is supportive of holding large quantities of CO₂.

For distances up to 1,000 km (about 621 miles), pipelines are the preferred choice for CO₂ transport. In fact, CO₂ pipeline transport is not new. The current system of CO₂ pipelines consists of 50 individual pipelines with a combined length of more than 4,500 miles. Most of these pipelines connect natural sources of CO₂ with oil fields for enhanced oil recovery. Over 68 million metric tons (MMtCO₂) are transported through this network each year, but as industrial CO₂ capture increases, the network of pipelines will grow, too.

While pipelines are a proven technology in the oil and gas industry, there are challenges for developing a large pipeline infrastructure. Developing infrastructure will be costly. The location of pipelines will influence overall costs of CCUS. Engineers need to determine large-scale network requirements, and design pipelines and routes that will be safe through all types of terrain. Unlike oil and gas, CO₂ is non-explosive, non-hazardous, and non-toxic, and is not ignitable. Risks associated with CO₂ pipeline transport are expected to be less than those posed by oil and gas pipelines already in use.

Existing CO₂ Pipelines



Data: U.S. Department of Energy's National Energy Technology Laboratory

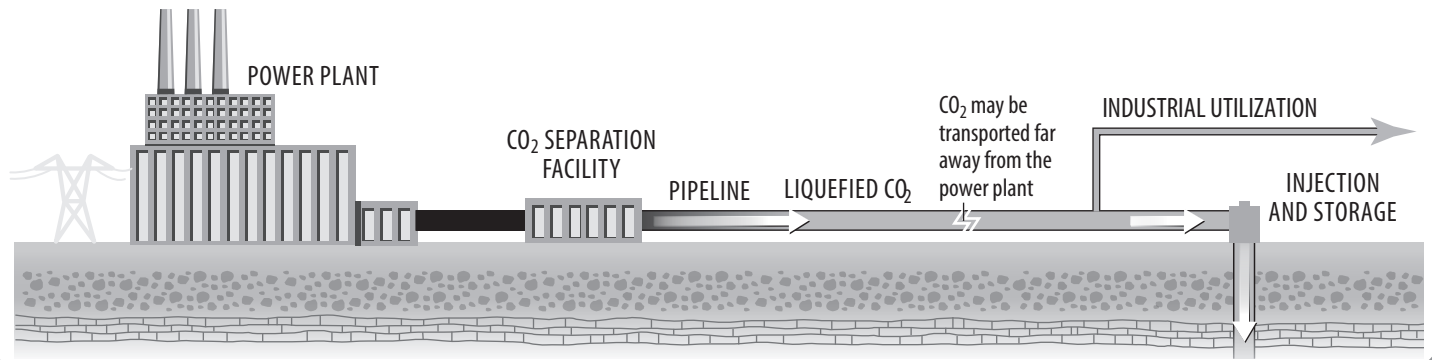
Risks are low, but safeguards along a CO₂ pipeline will need to be in place to monitor for leaks. Procedures need to be implemented to protect against overpressure, and to stop or control CO₂ releases should they arise. A small CO₂ leak would self seal as it froze and would not pose an immediate danger. In concentrations of seven to ten percent (by volume in air), CO₂ is dangerous to human health. When CO₂ is released from a pipeline it is denser than air and stays along the ground settling into low spots. In most conditions,

the CO₂ would quickly transform into a gas and be diluted and dispersed with the wind.

The food and beverage industry currently uses mostly tanker trucks to transport CO₂. However, trucks and rail cars will be uneconomical for large scale CO₂ transportation. Some CO₂ is transported by pipeline. In the U.S., pipelines are expected to transport all of the captured CO₂. In other parts of the world, engineers are considering the possibility of using ships for transporting smaller amounts of CO₂.

Carbon Capture, Utilization, and Storage Overview

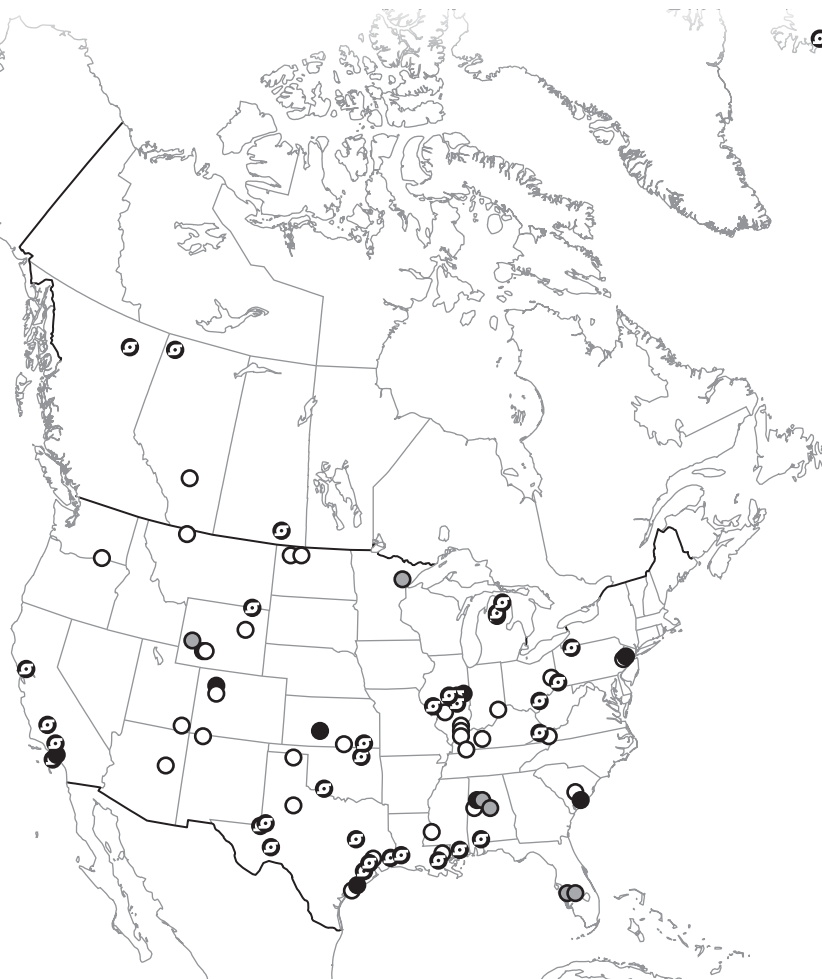
Carbon dioxide from a power plant or industrial facility will be separated from other flue gases at a separation facility on site. It will then be pressurized into a liquid and transported via pipeline to be used in a new application or in enhanced hydrocarbon recovery. It could also be sent underground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



Carbon Capture, Utilization, and Storage Projects

- Site Characterization
- Capture
- Capture and Storage
- Storage

Data: U.S. Department of Energy
National Energy Technology
Laboratory



Step Three: Utilization

One way to mitigate the amount of CO₂ entering the atmosphere is to find other uses for the gas. For a long time CO₂ has been used to carbonate beverages, as the active ingredient in fire extinguishers, and in refrigeration. Most current and potential uses of CO₂ tend to be on a small scale, however, and they also typically emit the CO₂ into the atmosphere after its use. Scientists are studying ways that CO₂ can be used in larger scale applications, and in ways that do not produce more CO₂ than what is trying to be saved from entering the atmosphere originally. There are four main CO₂ utilization research areas: enhanced fuel recovery, cement, polycarbonate plastics, and mineralization.

ENHANCED FUEL RECOVERY

Oil and gas are fuels that we use everyday. **Enhanced fuel recovery** utilizes CO₂ in oil and gas fields to increase production. Enhanced fuel recovery is more commonly referred to as enhanced oil recovery (EOR). It can also be called enhanced gas recovery (EGR), but this area is not as developed as EOR. Studies of EGR potential are ongoing.

In operating oil fields that are slowing production, CO₂ is injected into the wells as a liquid. Some of the CO₂ dissolves in the oil and increases the bulk volume while decreasing the viscosity. This allows the oil to flow toward the well bore and be pumped to the surface. This process of EOR allows for an additional 10-15 percent of oil to be recovered from existing wells.

Technology for EOR is already in use. Over 63 million metric tons of CO₂ are injected underground each year for EOR, but more than 80% of this CO₂ comes from naturally occurring geologic formations. Most of the operations capable of conducting EOR are located close to a point source of CO₂ emissions or a natural reservoir. Using CO₂ for EOR has the advantage of having revenue associated with the CO₂. The costs for storage are offset by revenues from the additional oil and gas produced.

CEMENT

Cement manufacturing is an energy intensive project that usually produces a large amount of CO₂. Scientists are working to develop a process that consumes CO₂ from onsite flue gases and local combustion sources, then to repurpose it as part of the concrete curing process, which will sequester the carbon dioxide for many years.

POLYCARBONATE PLASTICS

Carbon dioxide can be combined with traditional monomers, such as ethylene and propylene, to produce polycarbonates such as polyethylene carbonate and polypropylene carbonate. Polycarbonates can be used in coatings, plastic bags, and laminates. This use of CO₂ is a potential semi-permanent storage of carbon dioxide depending on the product's life cycle end stage.

MINERALIZATION

Naturally occurring alkaline and alkaline-earth oxides react chemically with CO₂ to produce minerals such as calcium carbonate (CaCO₃) and magnesium carbonate (MgCO₃). These minerals are highly stable and there is little concern that the CO₂ they contain would be released back into the atmosphere. Carbonates can be used as filler materials in paper and plastic products. They can also be used in construction. However, the mineralization process is slow, and unless the reaction occurs in an existing place, there is a large volume of rock to move.

Uses for CO₂

Carbon dioxide is currently used in a variety of ways. Most of these materials currently utilize naturally occurring CO₂. Research is underway on how to use CO₂ captured from stationary sources in some of these products.

BIOLOGICAL CONVERSION

- Fuels
- Food

EXTRACTANT

- Flavors/Fragrances
- Decaffeination

MINERALIZATION

- Carbonates

CHEMICALS

- Liquid fuels
- Fertilizer

REFRIGERANTS

- Refrigeration
- Dry ice

INERTING AGENTS

- Blanket products
- Protective carbon powder
- Shield gas in welding

FIRE SUPPRESSION

- Fire extinguishers

PLASTICS

- Polycarbonate
- Polymers

ENHANCED FUEL RECOVERY

- Oil
- Gas

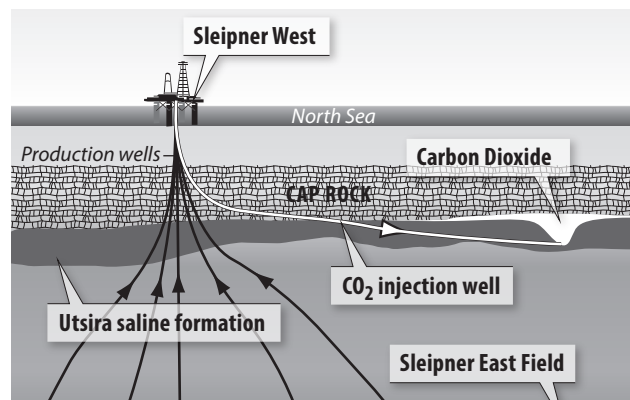
FOOD/PRODUCTS

- Carbonated beverages

MISCELLANEOUS

- Injected into metal castings
- Added to medical O₂ as a respiratory stimulant
- Aerosol can propellant
- Dry ice pellets used for sand blasting
- Red mud carbonation

Oil and Gas Production and Exploration



In the North Sea, Statoil, an international energy company, has been capturing and storing CO₂ from natural gas production since 1996. Captured directly from natural gas production, CO₂ is stored 2,625 feet (800 m) below the seabed. Over 14 million metric tons of CO₂ have been stored inside the Utsira formation since the project began.

Step Four: Geologic Storage

Determining a suitable location for CO₂ storage depends on a thorough site assessment. Sites are evaluated for their **reservoir capacity**, injectivity rates, and abilities to contain CO₂. Using a variety of tools, geologists study the area to make sure the reservoir is capable of containing the CO₂ indefinitely.

CO₂ will be injected as a liquid into porous rock formations that hold, or once held, fluids. Injecting CO₂ deeper than 800 meters will allow the natural pressure of the Earth to keep CO₂ in a liquid state, which makes it less likely to migrate out of the formation.

Currently, there are a few potential reservoirs for storing significant amounts of CO₂ within the Earth—oil and gas fields, deep saline formations, and unmineable coal seams. The capacity estimates for each of these reservoirs continue to evolve as researchers learn more about each area. Other options for storage include basalt and organic rich shale formations.

DEPLETED OIL AND GAS FIELDS

Using depleted oil and gas **reservoirs** without enhanced oil recovery is another option for CO₂ storage, but there are no end use cost benefits. The advantage with this option is that the geology of the reservoirs is well understood, and for hundreds of thousands of years they trapped liquids and gases, proving the structural integrity of the reservoir. Because these are depleted reservoirs, the infrastructure and wells from oil and gas extraction are already in place. It may be possible to convert these for transporting the CO₂ into the reservoir. If not properly capped, however, the same wells may be a conduit for CO₂ release. Usually these reservoirs are quite a distance from the CO₂ source so constructing pipelines to connect the source to the reservoir could be costly.

DEEP SALINE FORMATIONS

The largest potential capacity for CO₂ storage is deep saline formations. In these geologic formations, salt water, called brine, is stored in the rocks' pores and is unsuitable as drinking water or for agriculture. Saline formations are found both onshore and offshore (sub-sea). Saline reservoirs are common throughout the U.S. and have a higher probability of being located closer to point sources for CO₂ than oil and gas reservoirs.

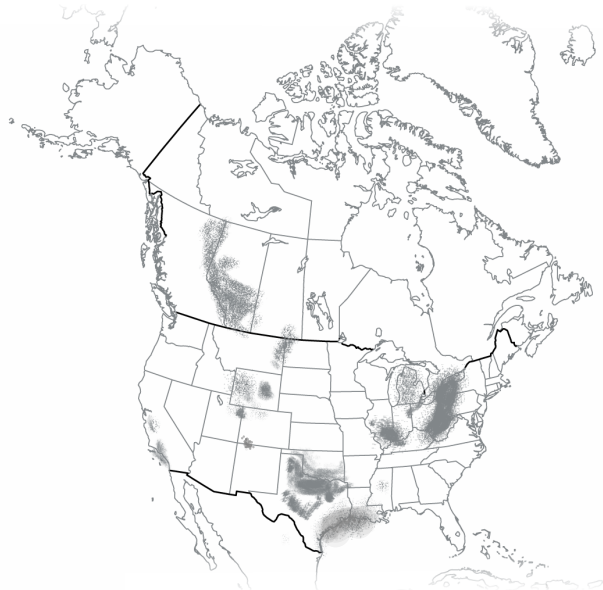
When injected into the brine, CO₂ is expected to eventually dissolve and later mineralize to become part of the rock formation. Since 1996, the Sleipner Project in the North Sea has been utilizing this technology. Over 1 million metric tons (1MMt) of CO₂ is stored each year in the Utsira formation, a sandstone reservoir below the sea that is 200-250 m (650-820 ft) thick and contains saline fluids. The CO₂ is trapped below a very thick layer of ceiling rock. There are no signs that the CO₂ has leaked out from the formation, and researchers believe that the CO₂ will dissolve into the saline.

Carbon Sequestration Atlas Estimates, 2012 (Million Metric Tons)

Oil and Gas Fields	226,000
Deep Saline Formations	2,102 - 20,093
Unmineable Coal Seams	56,000 - 114,000

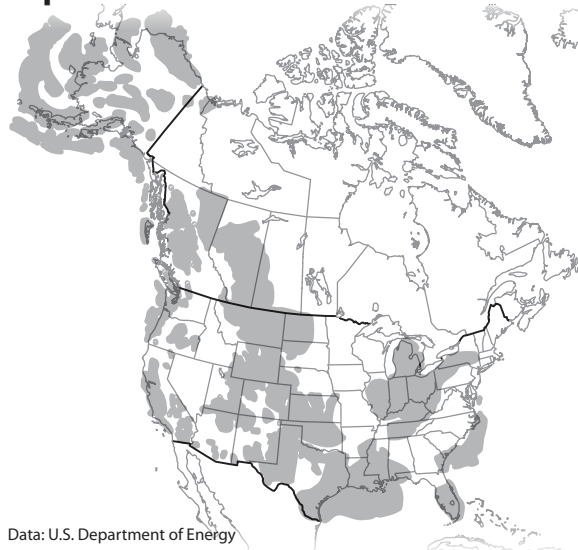
Data: Department of Energy

North American Oil and Gas Reservoirs



Data: U.S. Department of Energy's National Energy Technology Laboratory

Deep Saline Formations



Data: U.S. Department of Energy

Canadian Central Plains Provinces Sequestration Atlas Estimates 2012 (Million Metric Tons)

Oil and Gas Fields	18,000
Deep Saline Formations	81,000 - 286,000
Unmineable Coal Seams	29,000

The United States and Canada share the longest unguarded border in the world. As a result, many of the geological formations in the northern portions of the U.S. that are suitable for carbon dioxide storage are also found in Canada. Therefore, some of the regional partnerships for CCUS projects in the U.S. include Canadian provinces.

UNMINEABLE COAL SEAMS

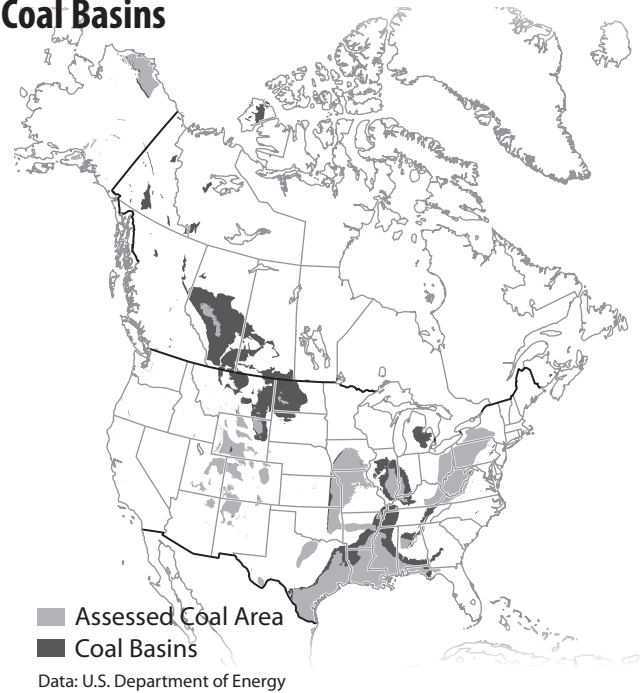
The U.S. has the largest recoverable coal reserves in the world. Even so, with today's technology a very high percentage of coal resources remain unmineable. The U.S. Department of Energy estimates unmineable coal **seams** in the U.S. have more potential capacity for CO₂ storage than oil and gas fields.

Methane is a gas commonly found trapped in coal seams. CO₂ will adhere to coal more tightly than methane does. For every methane molecule released, three to thirteen CO₂ molecules can be adsorbed to the coal. This means CO₂ could be injected into a coal seam and the methane would be displaced and potentially recovered at the surface as a source of revenue. This is called enhanced coalbed methane recovery (ECBM). Burning methane releases CO₂, but there still is a net storage of CO₂ in the unmineable coal seam.

Whether storing CO₂ in unmineable coal seams for use with ECBM, or using the seam as a storage site without ECBM, unmineable coal seams are often located near large CO₂ point sources, which would reduce transportation distances.

Geologic storage solutions are further along in development than other storage options. Yet studies, computer simulations, and physical research are being conducted on mineral carbonation.

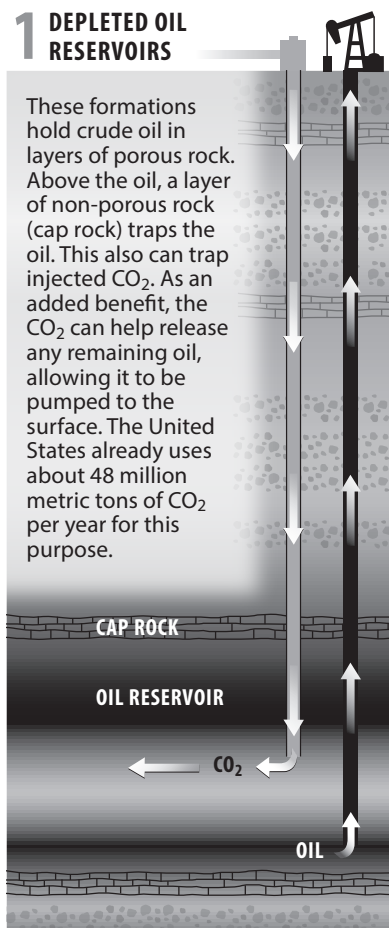
Coal Basins



Strategies for Geologic Storage of Carbon Dioxide

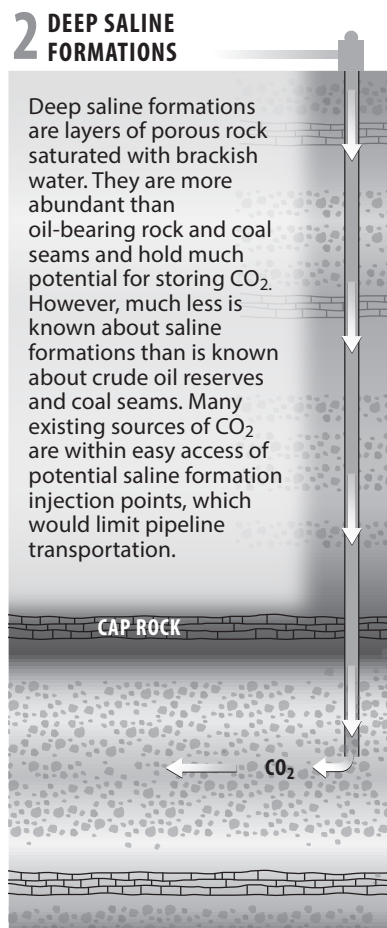
1 DEPLETED OIL RESERVOIRS

These formations hold crude oil in layers of porous rock. Above the oil, a layer of non-porous rock (cap rock) traps the oil. This also can trap injected CO₂. As an added benefit, the CO₂ can help release any remaining oil, allowing it to be pumped to the surface. The United States already uses about 48 million metric tons of CO₂ per year for this purpose.



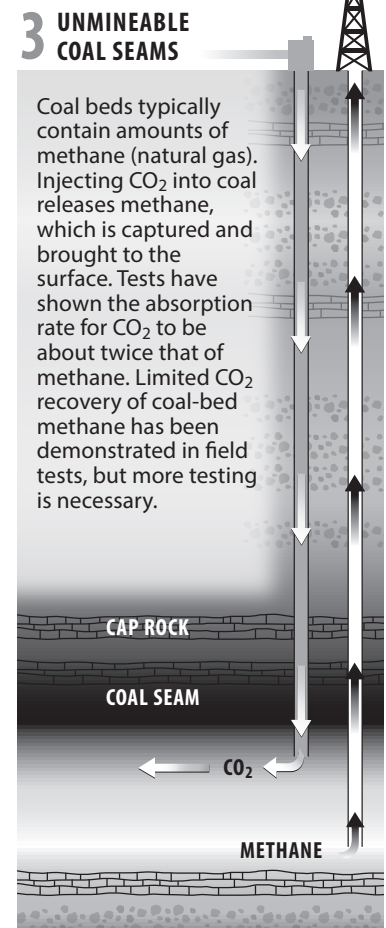
2 DEEP SALINE FORMATIONS

Deep saline formations are layers of porous rock saturated with brackish water. They are more abundant than oil-bearing rock and coal seams and hold much potential for storing CO₂. However, much less is known about saline formations than is known about crude oil reserves and coal seams. Many existing sources of CO₂ are within easy access of potential saline formation injection points, which would limit pipeline transportation.



3 UNMINEABLE COAL SEAMS

Coal beds typically contain amounts of methane (natural gas). Injecting CO₂ into coal releases methane, which is captured and brought to the surface. Tests have shown the absorption rate for CO₂ to be about twice that of methane. Limited CO₂ recovery of coal-bed methane has been demonstrated in field tests, but more testing is necessary.



Redrawn with permission from *The Columbus Dispatch*, originally published November 6, 2007

BASALT FORMATIONS

Given thousands, or millions, of years CO₂ will naturally react to its surroundings and convert into CaCO₃, or limestone. In this state, CO₂ is solid and stable. It no longer cycles in and out of the atmosphere. Scientists are trying to speed up this process by combining CO₂ with minerals such as olivine or serpentine creating a solid, and then storing the new solid in a repository.

In order to transform CO₂ into a solid carbonate, reactant minerals need to be mined, crushed, milled, and transported to a processing plant. These activities are energy intensive and release CO₂ in the process. Large amounts of silicate oxide materials are needed, as much as 3.7 metric tons, to store one ton of CO₂.

After the reactant minerals are ready they are piped into a concentrated CO₂ stream. Solid carbonate particles can then be separated and stored. The overall process is already applied on small scales and is in the early phase of development on larger scales.

Another mineral carbonation project may be to inject CO₂ in situ, or "in place." Injecting CO₂ directly into basalt formations would allow the CO₂ to react with the rock over time. Flood basalts are the result of volcanic eruptions that covered large areas of land with lava. Flood basalts are located around the world and have a high porosity and permeability, which make them good candidates for storing CO₂. Research is beginning in the flood basalts of the Columbia River Plateau in the Pacific Northwest.

ORGANIC-RICH SHALE BASINS

Shale is a sedimentary rock formed from silicate minerals that degrade into clay particles over the course of millions of years. Shales tend to form structures resembling stacked plates which limits their vertical permeability, trapping fluids beneath them. Shales are often used as a confining zone or cap rock in geological storage.

CCUS Costs

In order to mitigate climate change, CCUS technologies need to be a part of the solution. Utilizing or capturing CO₂ offers the most viable way to generate electricity at the current level, with resources we have readily available, and significantly reduce the CO₂ impact on the environment. There will be other environmental impacts and economic costs for pursuing CCUS technologies.

Capturing and compressing CO₂ with today's technology is energy intensive and will lower a power plant's efficiency. A power plant using current CCUS technologies will require 10-40 percent more energy than an equivalent plant without CCUS. For example, a power plant that generates 1,000 megawatts (MW) of electricity could require up to 300 MW for CCUS. Additional fuel will be needed to make up the energy requirement for capturing and compressing the CO₂. This means additional plants will need to be built to meet the consumer demand for electricity and the additional load requirements for CCUS. Even with the additional plants, net CO₂ capture is expected to be 80-90 percent.

Older power plants retrofitted with CCUS technology will see a greater reduction in overall efficiency than plants with CCUS technology incorporated into the design. The cost will also be higher to retrofit plants than for new builds. This is due to adapting plant configuration for a capture unit, a shorter lifespan of the plant compared to a new unit, and lost revenue when the plant is off-line undergoing the retrofit. Overall, the Department of Energy

Basalt Formations



U.S. Average Levelized Costs (\$/Megawatt-hour) for Plants Entering Service in 2019

Conventional Coal	\$95.60
Advanced Coal with CCUS	\$147.40
Natural Gas-fired	
Conventional Combined Cycle	\$66.30
Advanced CC with CCUS	\$91.30
Advanced Nuclear	\$96.10
Wind	\$80.30
Solar PV	\$130.00
Solar Thermal	\$243.10
Geothermal	\$47.90
Biomass	\$102.60
Hydropower	\$84.50

Data: Annual Energy Outlook 2012, EIA

estimates that the cost of electricity would increase 80 percent if current CCUS technologies were used to retrofit existing pulverized coal power plants. In addition, the capture technology requires a great deal of physical space. Many plants may not have the physical space in which to build the capture unit.

The use of CO₂ for EOR is already occurring, and the demand for CO₂ is higher than the supply. Potential for CO₂ use with EOR is small compared to other geologic storage options, but a need exists right now. In the short term, EOR is believed to be a promising market for CO₂. In the long term, however, the capacity of this reservoir is relatively small and few companies will be able to take advantage of selling CO₂ to oil and gas companies for EOR purposes.

Most current demonstration projects are receiving partial funding from the U.S. Department of Energy. The American Recovery and Reinvestment Act of 2009 included \$3.4 billion for CCUS related projects and programs. Federal incentives like this help companies pursue CCUS technologies as they move from demonstration projects to implementation at commercial scale.

It is expected that costs will be high for the first few plants and decrease as the demand for CCUS technology grows. Up to 80 percent of the costs are related to capture and compression.

Currently there are no requirements for utilities and independent power producers to regulate CO₂ emissions. Because the costs of new CCUS technologies are not recoverable in electric rates (e.g., customer's electric bills) until CO₂ is regulated, few companies will be financially able to spend the money to integrate CCUS technology into power plants. There are proposals before Congress that will require utilities and independent power producers to decrease their CO₂ emissions. If reducing CO₂ emissions becomes a requirement, the costs of adding CCUS technology to retrofit plants or build new plants will be passed on to the consumers.

While retrofitting pulverized coal plants will be the most costly, the ultimate goal for the U.S. Department of Fossil Energy's Innovations for Existing Plants program is to capture 90 percent of CO₂ emissions while adding less than a 10 percent increase for the cost of electricity for consumers.

CCUS Safety

As CCUS pilot and demonstration projects progress toward commercial scale projects, safety is a key component in all stages.

There are thousands of miles of CO₂ pipelines in the U.S., the first of which was the Canyon Reef Carriers Pipeline, which began operation in 1972. The Canyon Reef Carriers Pipeline is located in Surry County, TX and was built to bring CO₂ from Shell Oil Co. gas processing plants to the Texas Val Verde Basin.

CO₂ pipelines, as with natural gas and petroleum pipelines, are regulated by the U.S. Department of Transportation's Office of Pipeline Safety. While CO₂ is a non-flammable gas, CO₂ pipelines have many of the same safety requirements as pipelines carrying crude oil and gasoline. For twenty years, from 1986-2006, there were twelve leaks in CO₂ pipelines. None of these incidents resulted in injuries to people. Transporting CO₂ by pipeline is a safe transportation option.

Selecting an appropriate geologic storage site is an important factor in reducing risks associated with CO₂ storage. A suitable site will contain porous rocks that will trap the CO₂. Natural mechanisms in the porous rock will contain the CO₂ within its pore spaces. When CO₂ interacts with the brine (salt water) found in the permeable rock, the CO₂ will eventually dissolve. The solution becomes a weak acid, which over time forms new minerals binding the CO₂ to rocks permanently.

The permeable rock space where CO₂ is stored is capped by an impermeable cap rock. This restricts any upward movement of the CO₂. In addition, the reservoirs and wells are closely monitored. Scientists use 4D seismic surveys with temperature and pressure sensors to monitor and map the CO₂ as it is injected and once it is underground.

Those involved with CCUS pilot and demonstration projects are committed to developing safe technologies for capture, transport, utilization, and storage.

Conclusion

Many uncertainties remain about the feasibility of CCUS at the commercial scale. Incorporating additional CCUS technology into existing plants and new designs will be expensive. Infrastructure for transporting CO₂ needs to be built. Appropriate geologic formations for storage need to be identified. Laws regulating who is responsible when CO₂ passes through multiple states, and for

Average Price of Electricity by State, 2012

LEAST EXPENSIVE	CENTS / kWh	MOST EXPENSIVE	CENTS / kWh
Washington	8.67	Hawaii	36.99
North Dakota	9.10	New York	18.84
Idaho	9.37	Alaska	18.19
Louisiana	9.39	Connecticut	17.58
Arkansas	9.51	Vermont	17.15
West Virginia	9.52	California	16.39
Oklahoma	9.62	New Hampshire	16.36
Kentucky	9.71	Massachusetts	15.73
Oregon	9.94	New Jersey	15.72
Tennessee	10.04	Rhode Island	15.47

Data: Energy Information Administration



Image courtesy of Department of Energy

the CO₂ stored underground, need to be written. These are the challenges in moving CCUS plants from demonstration phases to commercial capacities. However, the research that is being conducted in laboratories and at small scale facilities is promising.

Managing **anthropogenic** or man-made sources of CO₂ is important on a worldwide scale. More than 100 countries signed the Kyoto Protocol in 1997, agreeing to work toward stabilizing greenhouse gas levels in the atmosphere to prevent human impact on the world's climate. If nothing is done, energy-related CO₂ emissions are forecasted to be 39.3 billion metric tons by 2030. The U.S. alone will emit approximately 8,000 million metric tons of CO₂ by the year 2030 without significant CO₂ mitigation.

It will take many different CO₂ management styles to reduce CO₂ atmospheric levels, including improving efficiency, lowering demand, and increasing the use of renewable energy sources; yet these tactics will not reduce emissions enough. Implementing technologies such as CCUS at fossil fuel power plants gives us the ability to meet rising energy demand while being more environmentally responsible.



Carbon Dioxide and CCUS KWL Chart

What I Think I Know

What I Want to Know

What I Learned



Modeling Combustion

Materials

- Molecular modeling kit (or similar objects)

Procedure

1. Use the spheres to build a molecule of methane, CH₄. Draw the model below:

2. Build two oxygen (O₂) molecules. Draw the model below:

3. In combustion, thermal energy + oxygen + hydrocarbons releases energy we can use. It also releases other by-products. Use your models to help you balance the equation:



Draw the products of combustion below:



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 driving 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 drive or ride 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 the amount of carbon dioxide emitted from our vehicles?
3. What might be some options for reducing the amount of carbon dioxide emitted by the transportation sector?



Properties of CO₂

What are the properties of CO₂ as a gas? Record your observations below.



Separating Mixtures

Problem

You have been given 100 g of a gravel/sand/salt mixture. You need to use your understanding of physical properties to recover the sand from this mixture.

 **Materials** *Make a list of the materials you will need:*

- 100 g of Gravel/salt/sand mixture



Procedure

1. Make a plan to recover the sand, describe this plan below.
2. Implement your plan. Take notes about what you did and any changes you made along the way.
3. Record the amount of sand you were able to recover. Ask your teacher to tell you the amount of sand you originally were given in the mixture.
4. Compare the amount of sand you recovered to the known amount. Calculate your percent error.

The Plan

Implementing the Plan

Data

Amount of sand recovered:

Calculate your percent error for recovering sand:

$$\text{Percent Error} = \left| \frac{\text{Measured Value} - \text{Actual Value}}{\text{Actual Value}} \right| \times 100$$

Conclusions

1. What physical properties of the materials allowed you to recover the sand?
2. How successful were you at recovering the sand? What changes would you make to be able to recover more sand?



Exploring Porosity

Question

Which size material will have the greatest porosity?

Hypothesis

Make a hypothesis to address the question using the following format: If (independent variable) then (dependent variable) because ...

Materials

- 350 cm³ Small gravel
- 350 cm³ Medium gravel
- 350 cm³ Large gravel
- 100 mL Graduated cylinder
- 3 – 600 mL Beakers
- Water (can be dyed with food coloring)
- Safety glasses

Procedure

1. Fill one beaker to the 350 cm³ mark with large gravel, fill a second beaker with 350 cm³ of medium gravel, and fill the third beaker with 350 cm³ of small gravel.
2. Fill the graduated cylinder with 100 mL of water dyed with food coloring.
3. Slowly pour water into the first beaker until the water just reaches the top of the rocks. Record exactly how much water you poured into the beaker. If you need more than 100 mL of water, fill the graduated cylinder again.
4. Follow step 3 for the other two beakers.
5. Calculate the porosity of the three materials using this formula:

$$\text{Porosity} = \frac{\text{volume of water}}{\text{volume of material}} \times 100.$$

*Reminder 1 cm³ = 1 mL

Data

TYPE OF MATERIAL	VOLUME (mL) OF WATER Poured	VOLUME (cm ³) OF MATERIAL	PERCENTAGE OF PORE SPACE IN MATERIAL
Large gravel			
Medium gravel			
Small gravel			

Conclusions

1. Did the results allow you to confirm or reject your hypothesis? Explain using experimental data.
2. How does porosity affect the ability of a material to contain carbon dioxide?



Enhanced Fuel Recovery Model

OPTION A: DRY ICE

Question

How does using carbon dioxide allow additional oil and gas to be recovered from reservoirs that are slowing production?

Hypothesis

Make a hypothesis to address the question using the following format: If (independent variable) then (dependent variable) because ...

Materials

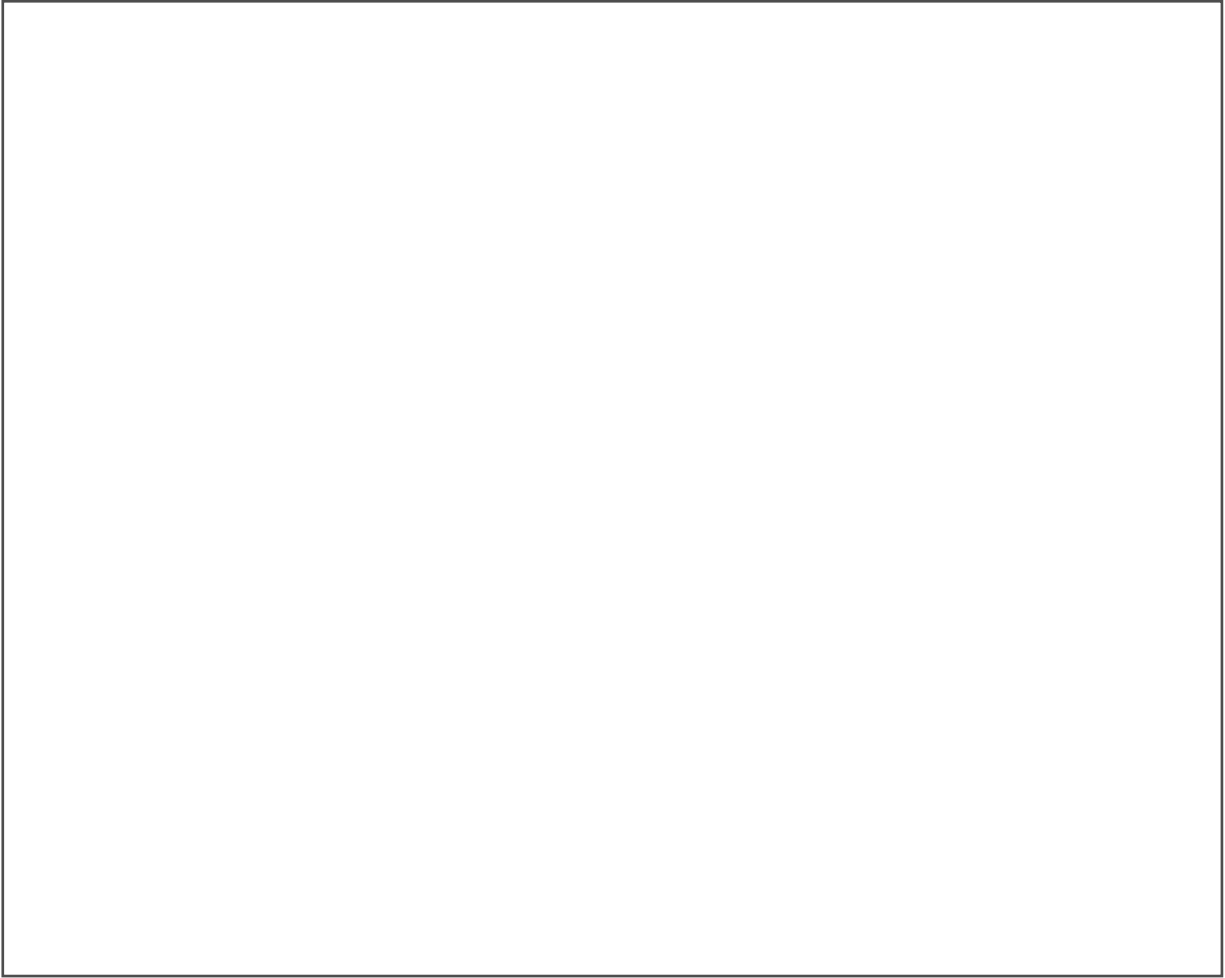
- 1 Mason jar lid with two ¼" holes
- 1 Mason jar lid with one ¼" hole
- 1 Empty water bottle
- 2 24" x ¼" Tubing
- 1 Piece of dry ice, about the size of an ice cube
- Assorted rocks, sand, and marbles
- 150 mL Vegetable oil or lamp oil
- 350 mL Water
- 1 Dark color of food dye
- Silicon sealant
- Tongs
- Gloves
- Safety glasses
- Tape

Procedure

1. Review *Dry Ice Safety* rules with your teacher and your group members.
2. Put one piece of tubing through the lid with two holes. Slide the tubing all of the way down into the bottom of one jar. Tape the tubing to the inside of the jar to hold it in place. This jar will serve as your **reservoir jar**. Place the other end of this tube into the water bottle. The water bottle will serve as your **production bottle**.
3. Insert the second piece of tubing about 5 cm through the second hole in the lid for the **reservoir jar**. Insert the other end of this tubing about 5 cm into the lid with one hole for the other empty mason jar. The jar with one hole in the lid will serve as your **CO₂ injection jar**.
4. Secure the tubing in both lids with sealant. (If time permits, allow the sealant to dry prior to executing the experiment for better results.)
5. Fill the **reservoir jar** with marbles, rocks, and/or sand. Leave about an inch of open space at the top of the **reservoir jar**.
6. Add 150 mL of oil to the **reservoir jar**. This represents crude oil stuck within the rocks below ground.
7. Fill the remainder of space in the **reservoir jar** with water, being careful to fill only up to the top of the rocks/marbles/sand. Dye the water with food coloring if you desire.
8. Secure the lid with two holes on the **reservoir jar** tightly.
9. Pinch off the tubing and gently rotate and mix the **reservoir jar**.
10. Using tongs, place a piece of dry ice into the **CO₂ injection jar** with one tube in its lid. Secure the lid tightly and be prepared for the **production bottle** to start filling up with recovered oil and water from the reservoir.

Observations

Draw a diagram of your reservoir model. Describe what is happening. Where is the CO₂ going? Where is the oil going? How much oil were you able to recover?



****** Conclusions

1. How does carbon dioxide allow for enhanced hydrocarbon recovery?

2. What are some of the benefits? What are some of the challenges?



Enhanced Fuel Recovery Model

OPTION B: EFFERVESCENT TABLETS

Question

How does using carbon dioxide allow additional oil and gas to be recovered from reservoirs that are slowing production?

Hypothesis

Make a hypothesis to address the question using the following format: If (independent variable) then (dependent variable) because ...

Materials

- 1 Mason jar lid with two ¼" holes
- 1 Mason jar lid with one ¼" hole
- 1 Empty water bottle
- 2 24" x ¼" Tubing
- Effervescent tablets
- Assorted rocks, sand, and marbles
- 150 mL Vegetable oil or lamp oil
- 350 mL Water
- 1 Dark color of food dye
- Silicon sealant
- Tongs
- Gloves
- Safety glasses
- Piece of tissue paper
- Tape

Procedure

1. Put one piece of tubing through the lid with two holes. Slide the tubing all of the way down into the bottom of one jar. Tape the tubing to the inside of the jar to hold it in place. This jar will serve as your **reservoir jar**. Place the other end of this tube into the water bottle. The water bottle will serve as your **production bottle**.
2. Insert the second piece of tubing about 5 cm through the second hole in the lid for the **reservoir jar**. Insert the other end of this tubing about 5 cm into the lid with one hole for the other empty mason jar. The jar with one hole in the lid will serve as your **CO₂ injection jar**.
3. Secure the tubing in both lids with sealant. (If time permits, allow the sealant to dry prior to executing the experiment for better results.)
4. Fill the **reservoir jar** with marbles, rocks, and/or sand. Leave about an inch of open space at the top of the **reservoir jar**.
5. Add 150 mL of oil to the **reservoir jar**. This represents crude oil stuck within the rocks below ground.
6. Fill the remainder of space in the **reservoir jar** with water, being careful to fill only up to the top of the rocks/marbles/sand. Dye the water with food coloring if you desire.
7. Secure the lid with two holes on the **reservoir jar** tightly.
8. Pinch off the tubing and gently rotate and mix the **reservoir jar**.
9. Pour 350 mL of water into the **CO₂ injection jar**.
10. Make a packet for the 6 effervescent tablets out of a single piece of tissue paper and twist it closed.
11. Holding the lid set-up of the **CO₂ injection jar** close to the mouth of the jar, quickly drop the tissue paper packet into the **CO₂ injection jar**.
12. Immediately secure and tighten the lid of the **CO₂ injection jar**.
13. The tissue paper will get wet, permitting the tablets to fizz. Swirl the jar around gently to encourage all of the tablets to dissolve. Be prepared for the **production bottle** to start filling up with recovered oil and water from the reservoir.

Observations

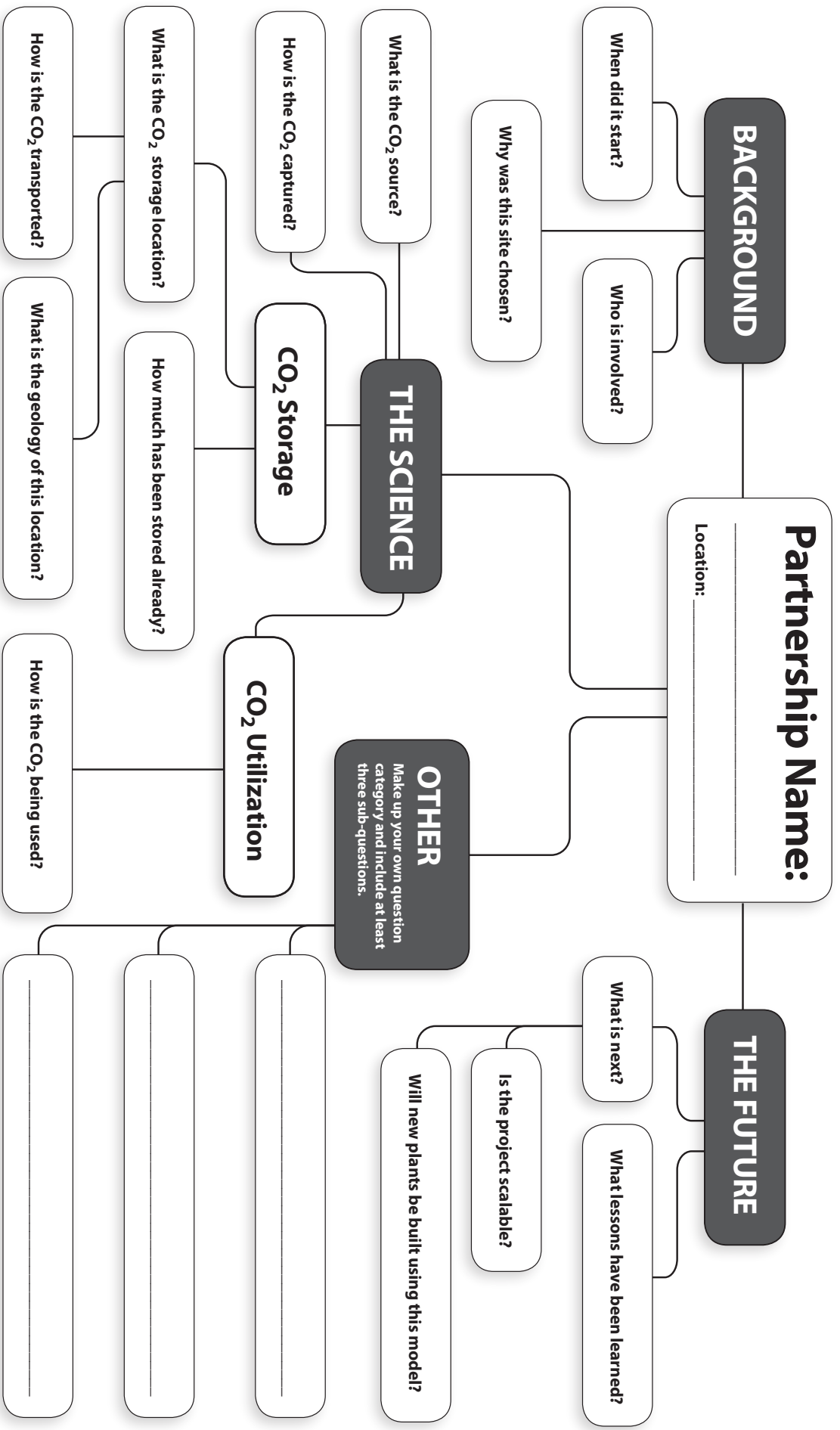
Draw a diagram of your reservoir model. Describe what is happening. Where is the CO₂ going? Where is the oil going? How much oil were you able to recover?



****** Conclusions

1. How does carbon dioxide allow for enhanced hydrocarbon recovery?

2. What are some of the benefits? What are some of the challenges?





Carbon Capture, Utilization, and Storage Glossary

absorption	the taking up and holding of a liquid or gas by a substance (a solid or liquid) through pores or gaps between molecules
anthropogenic	made or generated by a human or caused by human activity; used in the context of global climate change to refer to gaseous emissions that are the result of human activities, as well as other potentially climate-altering activities, such as deforestation
baseload	the minimum amount of power a utility must have available to its customers
carbon budget	the balance of the exchanges (incomes and losses) of carbon between carbon sinks (e.g., atmosphere and biosphere) in the carbon cycle, also called "carbon flux"
Carbon Capture, Utilization, and Storage (CCUS)	the fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes; also referred to as "carbon sequestration"
carbon cycle	all carbon sinks and exchanges of carbon from one sink to another by various chemical, physical, geological, and biological processes, also see <i>carbon sink</i> below
carbon dioxide (CO₂)	a colorless, odorless, non-poisonous gas that is a normal part of Earth's atmosphere; a product of fossil-fuel combustion as well as other processes; considered a greenhouse gas as it traps heat (infrared energy) radiated by the Earth into the atmosphere and thereby contributes to the potential for global warming; the global warming potential (GWP) of other greenhouse gases is measured in relation to that of carbon dioxide, which by international scientific convention is assigned a value of one (1)
carbon sink	a reservoir that absorbs or takes up released carbon from another part of the carbon cycle; the four sinks, which are regions of the Earth, within which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually including freshwater systems), oceans, and sediments (including fossil fuels)
climate change	a term used to refer to all forms of climatic inconsistency, but especially to significant change from one prevailing climatic condition to another; has been used synonymously with the term "global warming;" scientists tend to use the term in a wider sense inclusive of natural changes in climate, including climatic cooling
coal	a combustible rock whose composition consists of more than 50 percent by weight and more than 70 percent by volume of carbonaceous material; formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geologic time
coal gasification	the process of converting coal into gas, which involves crushing coal to a powder, which is then heated in the presence of steam and oxygen to produce a gas; the gas is then refined to reduce sulfur and other impurities and can be used as a fuel or processed further and concentrated into chemical or liquid fuel
combustion	chemical oxidation accompanied by the generation of light and heat
electric grid	the series of interconnected power and transmission lines that deliver electricity to consumers
emissions	anthropogenic releases of gases to the atmosphere; in the context of global climate change, they consist of radioactively important greenhouse gases (e.g., the release of carbon dioxide during fuel combustion)
energy carrier	a secondary source of energy; a source that requires another source to create it
enhanced fuel recovery	the recovery of oil and gas from reservoirs using means other than using natural reservoir pressure; generally results in the removal of increased amounts of oil from a reservoir when compared to employing methods using natural pressure or pumping alone
flue gas	gases that are produced through the combustion of a fuel, which are normally emitted into the atmosphere
fossil fuel	fuels (coal, oil, natural gas) that result from the compression of ancient plant and animal life formed over hundreds of millions of years
gasification	a method for converting coal, petroleum, biomass, wastes, or other carbon-containing materials into a gas that can be burned to generate power or processed into chemicals and fuels

greenhouse effect	the result of water vapor, carbon dioxide, and other atmospheric gases trapping radiant (infrared) energy, thereby keeping the Earth's surface warmer than it would otherwise be; greenhouse gases within the lower levels of the atmosphere trap this radiation, which would otherwise escape into space, and subsequent re-radiation of some of this energy back to the Earth, causing it to maintain higher surface temperatures than would occur if the gases were absent
greenhouse gases	those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving Earth's atmosphere; the net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface
metric ton (Mton)	a metric ton is equivalent to 1,000 kilograms, and is strictly speaking a megagram, being one million grams; a unit of weight equal to 2,204.6 pounds
natural gas	a gaseous mixture of hydrocarbon compounds, the primary one being methane
petroleum	liquid hydrocarbon mixtures including crude oil, lease condensate, unfinished oils, and refined products obtained from the processing of crude oil, and natural gas plant liquids
reserves, coal	quantities of unextracted coal that comprise the demonstrated base for future production, including both proved and probable reserves
reservoir	a porous and permeable underground formation containing an individual and separate natural accumulation of producible hydrocarbons (crude oil and/or natural gas), which is confined by impermeable rock or water barriers and is characterized by a single natural pressure system
reservoir capacity	the present total developed capacity (base and working) of the storage reservoir, excluding contemplated future development
seam	a bed of coal
sublimation	a change from the solid state to the gaseous state, without first passing through the liquid state
synthetic gas (syngas)	a manufactured mixture of gases including carbon monoxide (CO), CO ₂ , and hydrogen, that is created by a conversion of hydrocarbons at high temperatures
terrestrial sequestration	the net removal of CO ₂ from the atmosphere or the prevention of CO ₂ net emissions from the terrestrial ecosystems into the atmosphere; terrestrial ecosystems include forest lands, agricultural lands, biomass croplands, deserts and degraded lands, and boreal wetlands and peatlands



Carbon Capture, Utilization, and Storage 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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Hawaii Energy
Houston Museum of Natural Science
Idaho Power
Idaho National Laboratory
Illinois Clean Energy Community Foundation
Independent Petroleum Association of America
Independent Petroleum Association of New Mexico
Indiana Michigan Power – An AEP Company
Interstate Renewable Energy Council
James Madison University
Kentucky Clean Fuels Coalition
Kentucky Department of Education
Kentucky Department of Energy Development and Independence
Kentucky Power – An AEP Company
Kentucky River Properties LLC
Kentucky Utilities Company
Kinder Morgan
Leidos
Linn County Rural Electric Cooperative
Llano Land and Exploration
Louisiana State University Cooperative Extension
Louisville Gas and Electric Company
Maine Energy Education Project
Massachusetts Division of Energy Resources
Michigan Oil and Gas Producers Education Foundation
Miller Energy
Mississippi Development Authority–Energy Division
Mojave Environmental Education Consortium
Mojave Unified School District
Montana Energy Education Council
NASA
National Association of State Energy Officials
National Fuel
National Grid
National Hydropower Association
National Ocean Industries Association
National Renewable Energy Laboratory
Nebraska Public Power District
New Mexico Oil Corporation
New Mexico Landman’s Association
Nicor Gas – An AGL Resources Company
Northern Rivers Family Services
North Shore Gas
NRG Energy, Inc.
Offshore Energy Center
Offshore Technology Conference
Ohio Energy Project
Opterra Energy
Oxnard School District
Pacific Gas and Electric Company
Paxton Resources
PECO
Pecos Valley Energy Committee
Peoples Gas
Petroleum Equipment and Services Association
Phillips 66
PNM
Providence Public Schools
Read & Stevens, Inc.
Renewable Energy Alaska Project
Rhode Island Office of Energy Resources
River Parishes Community College
RiverQuest
Robert Armstrong
Roswell Geological Society
Salt River Project
Sandia National Laboratory
Saudi Aramco
Science Museum of Virginia
C.T. Seaver Trust
Shell
Shell Chemicals
Society of Petroleum Engineers
Society of Petroleum Engineers – Middle East, North Africa and South Asia
David Sorenson
Southern Company
Space Sciences Laboratory of the University of California Berkeley
Tennessee Department of Economic and Community Development–Energy Division
Tioga Energy
Toyota
Tri-State Generation and Transmission
TXU Energy
United States Energy Association
University of Georgia
United Way of Greater Philadelphia and Southern New Jersey
University of Nevada–Las Vegas, NV
University of North Carolina
University of Tennessee
University of Texas - Austin
University of Texas - Tyler
U.S. Department of Energy
U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy–Wind for Schools
U.S. Department of the Interior–Bureau of Land Management
U.S. Energy Information Administration
West Bay Exploration
West Virginia State University
Yates Petroleum Corporation