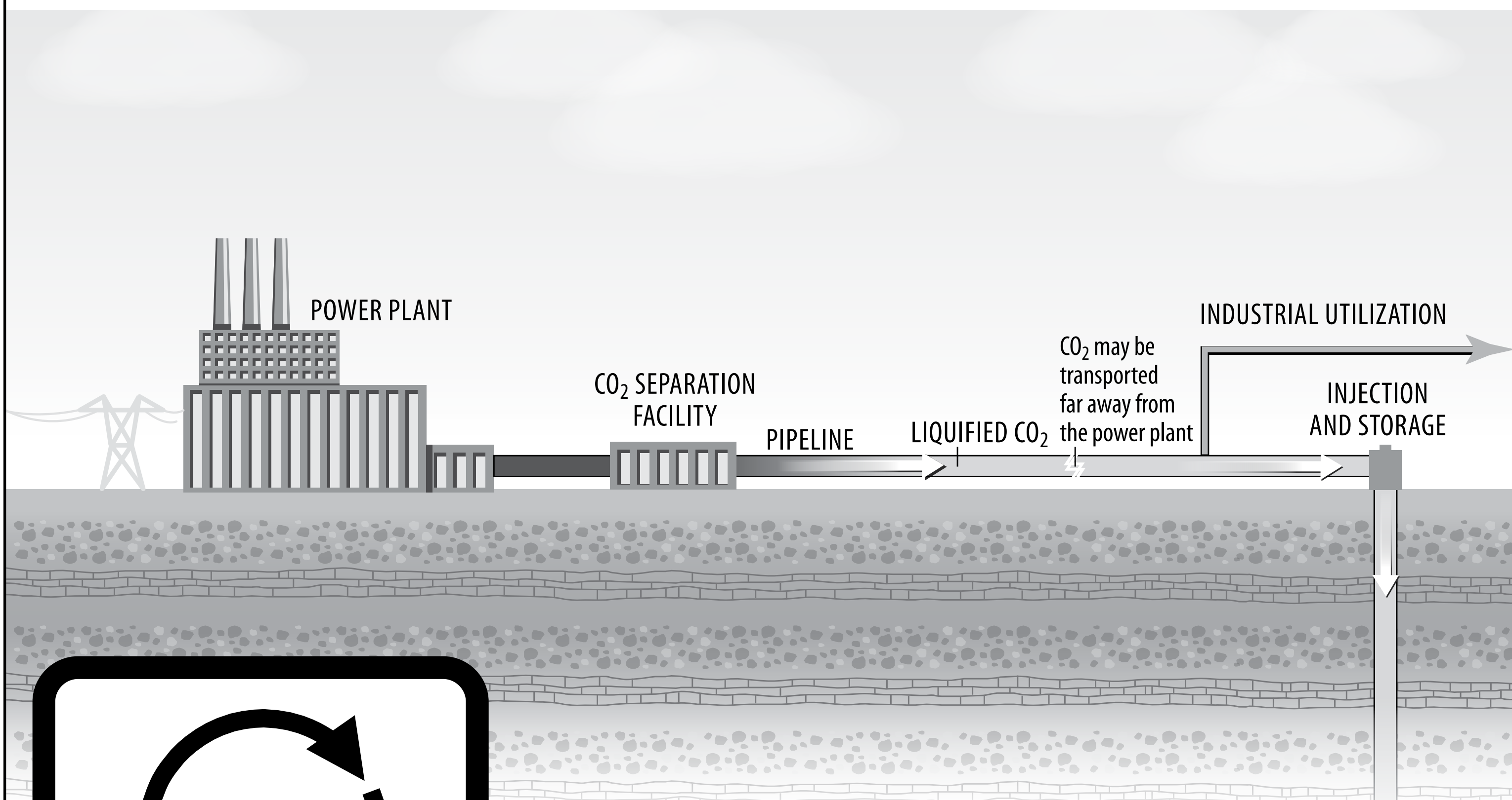
# Carbon Capture, Utilization and Storage

Background reading 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.




SYNTHESIS

**Grade Level:**

- Secondary

**Subject Areas:**

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

SYNTHESIS

ENERGY SOURCES

NEED
National Energy Education Development Project

2011-2012

# Teacher Advisory Board



# 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.

## Teacher Advisory Board Statement

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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## Energy Data Used in NEED Materials

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 in June of each year. Working in partnership with EIA, NEED includes easy to understand data in our curriculum materials. To do further research, visit the EIA web site at www.eia.gov. EIA's Energy Kids site has great lessons and activities for students at www.eia.gov/kids.

NEED
National Energy
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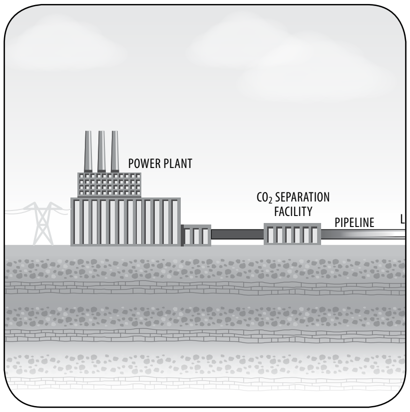



# Carbon Capture, Utilization and Storage

## Purpose

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 Carbon capture, utilization and storage 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.

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

## Table of Contents



SYNTHESIS

# Correlations to National Science Education Standards: Grades 9-12

This book has been correlated to National Science Education Content Standards.
For correlations to individual state standards, visit **www.NEED.org**.

## Content Standard A | *SCIENCE AS INQUIRY*

- **Abilities Necessary to do Scientific Inquiry**
  - Identify questions and concepts that guide scientific investigations.
  - Design and conduct scientific investigations.
  - Use technology and mathematics to improve investigations and communications.
  - Formulate and revise scientific explanations and models using logic and evidence.
  - Recognize and analyze alternative explanations and models.
  - Communicate and defend a scientific argument.

## Content Standard B | *PHYSICAL SCIENCE*

- **Structure and Properties of Matter**
  - Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.
  - Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.
- **Chemical Reactions**
  - Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies.
  - Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.

## Content Standard D | *EARTH AND SPACE SCIENCE*

- **Geochemical Cycles**
  - Movement of matter between reservoirs is driven by the Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

## Content Standard E | *SCIENCE AND TECHNOLOGY*

- **Understandings about Science and Technology**
  - Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.
  - Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
  - Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world.

# Correlations to National Science Education Standards: Grades 9-12

## Content Standard F | *SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES*

- **Natural Resources**
  - Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations.
  - The Earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed.
  - Humans use natural systems as resources. Natural systems have the capacity to reuse waste, but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

- **Environmental Quality**
  - Materials from human societies affect both physical and chemical cycles of the Earth.
  - Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the Earth.

- **Natural and Human-Induced Hazards**
  - Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change.
  - Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards—ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and the accuracy with which scientists and engineers can (and cannot) predict events are important considerations.

- **Science and Technology in Local, National, and Global Challenges**
  - Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges.

# Materials

| ACTIVITY | MATERIALS NEEDED | |
|---|---|---|
| **1: Modeling Combustion** | ***FOR EACH PAIR***<br>▪4 2″ Spheres (oxygen)<br>▪4 1″ Spheres (hydrogen)<br>▪1 1 ½″Spheres (carbon<br>▪16 Round toothpicks | |
| **2: Carbon Footprint** | ***FOR THE CLASS***<br>▪5 lb. Bag of charcoal briquettes<br>▪1 Tall, white kitchen trash bag<br>▪1 Plastic grocery bag<br>▪Paper towels<br>▪All purpose cleaning solution<br>▪1 Sheet white 8 ½″ x 11″ paper | |
| **3: Properties of $CO_2$** | ***FOR THE CLASS****<br>▪Trash bag<br>▪5-10 pounds of dry ice (keep in foam cooler until ready to use)<br>▪Pair of gloves<br>▪Tongs<br>▪Large, clear container<br>▪Plastic tray<br>▪Bottle of bubbles | ▪Bottle of water<br>▪Rubber glove or rubber balloon<br>▪Pipe cleaner<br>▪Tea light candle<br>▪Matches<br>▪8 oz. Plastic cup<br>▪Safety glasses<br>▪Water<br>**This activity can be done in small groups, adjust materials accordingly.* |
| **4: Separating Mixtures** | ***FOR EACH SMALL GROUP***<br>▪Sand<br>▪Gravel<br>▪Salt<br>▪Beakers | ▪Water<br>▪Balance<br>▪Variety of filter materials that may include screens, cheesecloth, newspaper, etc.<br>▪Safety glasses |
| **5. Exploring Porosity** | ***FOR EACH SMALL GROUP***<br>▪1 Bag of very small rocks<br>▪1 Bag of small gravel<br>▪1 Bag of medium gravel<br>▪1 100 mL Graduated cylinder | ▪3 500 mL Beakers<br>▪Water, dyed with dark food coloring<br>▪Safety glasses |
| **5: Enhanced Oil Recovery** | ***FOR DEMONSTRATION:***<br>▪Clear glass jar with tight lid<br>▪Water<br>▪Marbles<br>▪Pebbles<br>▪Stones<br>▪5 oz. Colored lamp oil or vegetable oil | ***FOR SMALL GROUPS***<br>▪2 Mason jars with lids<br>▪2 Pieces of 24″ by ¼″ tubing<br>▪5 oz. of Vegetable oil or lamp oil<br>▪8 oz. Water<br>▪1 Dark colored food dye<br>▪1 Piece of dry ice, about the size of an ice cube<br>▪Assorted rocks, sand, and marbles<br>▪Safety glasses<br>▪Tongs |
| **6: Researching Regional Sequestration Partnerships** | ***FOR EACH SMALL GROUP***<br>▪Computer and internet access | |

Please review *Dry Ice Safety* on page 15 before working with dry ice.
If you do not have access to dry ice you can produce carbon dioxide by combining baking soda and vinegar.

# Carbon Capture, Utilization and Storage

## Teacher Guide

## Background

Carbon capture, utilization and storage (CCUS) is a process designed to separate carbon dioxide ($CO_2$) out of the flue stream produced by coal, natural gas, and petroleum fired power plants. By isolating the $CO_2$, 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.

## Time

6-10 Class periods

## Introduction

### ✪ Objective

Students will begin to understand about the role of carbon dioxide in the environment, and how CCUS technologies will be employed to reduce the amount of carbon dioxide emissions from stationary sources electric power plants.

### Materials

- *Student Backgrounder*, pages 16-28
- *Carbon Dioxide and Carbon capture, utilization and storage KWL Sheet*, page 29

### Time

- 45 minutes

### ☑ Procedure

1. Ask students to fill out what they think they know, and questions they currently have, about carbon dioxide and carbon capture, utilization and storage on their KWL chart.
2. Students read the backgrounder and keep track of questions and new pieces of information they've learned through their reading.
3. Discuss the information with the class, let students share what they learned.

## Activity 1: Modeling Combustion

### ✪ Objective

Students will understand the molecular structure of carbon dioxide.

### Materials for Each Small Group

- 4 2″ Spheres (oxygen)
- 4 1″ Spheres (hydrogen)
- 1 1 ½″ Spheres (carbon)
- 16 Round toothpicks
- *Modeling Combustion* worksheet, page 30

### Time

- 45 minutes

### ☑ Procedure

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 ($CH_4$) is the simplest hydrocarbon molecule made of four hydrogen atoms and one carbon atom.

1. Ask students how energy is released from hydrocarbons. (We burn them.) Combustion requires a fuel source, oxygen, and heat.
2. Give students the *Modeling Combustion* worksheet. Let students work in pairs through modeling hydrogen, oxygen, methane, and the products of combustion.

### + Combustion Formulas

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

## Activity 2: Carbon Footprint

### Objective

Students will develop an understanding of individual carbon footprints.

### Materials for the Class

- 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 for each student
- *Carbon Footprint* worksheet, (page 31) for everyone

### Time

- 45 minutes

### Preparation

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

### Procedure

1. Break students into small groups to brainstorm a list of uses for $CO_2$ based on their findings from the homework assignment.
2. Based on the first activity, students should understand that $CO_2$ is released into the atmosphere during fossil fuel combustion. This includes combustion from fossil fueled power plants generating electricity, from manufacturing processes, and from the burning of fossil fuels in vehicles.
3. Explain that $CO_2$ is usually found in a gas form. It is colorless and transparent to light. Even though we know $CO_2$ impacts the environment, we do not always think about it because we cannot see it. Show students the bag of charcoal briquettes. The briquettes are made almost completely of carbon, so the briquettes will represent the amount of carbon in one gallon of gas. The average gallon of gasoline contains about five pounds of carbon. There are 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 problem 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 web site, 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 www.epa.gov/climatechange/emissions/ind_calculator.html. It will be most accurate if students have an energy bill from home they can reference.

## Activity 3: Properties of $CO_2$

### Objective

Students will understand properties of carbon dioxide.

### Materials for the Class

- Trash Bag
- 5-10 Pounds of dry ice (keep in foam cooler until ready to use)
- Pair of gloves
- Tongs
- Large, clear container
- Plastic tray
- Bottle of bubbles
- Bottle of water
- Balloon
- Pipe cleaner
- Tea light candle
- Matches
- 8 oz. Plastic cup
- Safety glasses
- *Properties of $CO_2$* worksheet, page 32
- *Dry Ice Safety,* page 15

### Time

- 45 minutes

### Preparation

- Cover work surface with plastic trash bag.
- Review *Dry Ice Safety* on page 15.
- 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. Review 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 container.
3. Explain that carbon dioxide ($CO_2$) is usually found in its gas form. However, it also can be found in a solid form and liquid form. Dry ice is frozen $CO_2$; it is $CO_2$ in solid form.
4. Ask students, "What happens when frozen water warms up?" (It melts and turns into a liquid.) Next ask, "What do you think happens when frozen $CO_2$ warms up?" Have students record their prediction in a science notebook. Have students observe the dry ice for a few minutes. Students should record observations using pictures and words in their science notebook. Ask students to explain what they are seeing. Discuss why $CO_2$ does not exist as a liquid at atmospheric pressure. Because, as solid $CO_2$ thaws, or sublimes, it transforms directly into a gas. $CO_2$ exists as a liquid only at great pressure.
5. Pour water onto the dry ice to produce $CO_2$ gas until the gas fills the container.
6. Blow bubbles into the large container. Have students record their observations in their science notebook and explain what is happening. After students have had time to write down their own thoughts, explain how $CO_2$ is denser than air. Since the bubbles are filled with air, they float on top of the $CO_2$ gas collected in the container.
7. Light a tea candle. Using the plastic cup collect some $CO_2$ gas and pour it over the candle. Students should record what happens and explain what they saw. Explain how $CO_2$ displaces less dense oxygen. The $CO_2$ is denser than air and pushes the oxygen away, the fire needs oxygen to continue burning so the fire is extinguished. This is why $CO_2$ is used in fire extinguishers.
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 in their science notebooks and explain what happened.

## Activity 4: Separating Mixtures

### ✪ Objective

Students will understand that physical properties are often used to separate mixtures into individual parts.

### Materials for Each Small Group

- Salt
- Sand
- Gravel
- Water
- Beakers
- Balance
- A variety of filter materials including screens cheesecloth, newspaper, etc.
- *Separating Mixtures* worksheet, page 33 (for everyone)
- Safety glasses (for everyone)

### Time

- 45 minutes

### 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.

### ☑ Procedure

1. Review the properties of carbon dioxide students observed in the previous investigation. Explain how scientists use the physical and chemical properties of $CO_2$ 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 denser than air. It is also more dense than nitrogen or pure oxygen. It is less dense than sulfur dioxide. Other physical properties of $CO_2$ 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 the other gases will do. (For example, how 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 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. Students need to develop a technique to use the physical properties of the materials to separate the sand from the other components of the mixture.
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. 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 understand how porosity rates influence whether or not a material is a good candidate for carbon dioxide storage.

### Materials for Each Small Group

- 1 Bag of very small rocks
- 1 Bag of small gravel
- 1 Bag of medium gravel
- 1 100 mL Graduated cylinder
- 3 500 mL Beakers
- Water, dyed with dark food coloring
- *Exploring Porosity* worksheet, page 34 (for everyone)
- Safety glasses (for everyone)

### Time

- 45 minutes

### Procedure

1. Review with students that porosity is the measure of the amount of empty space in a rock or sediment. Permeability describes how well a rock or sediment lets a fluid pass through.
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 Oil Recovery Model

## ✪ 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
- 5 oz. Colored lamp oil or vegetable oil

***FOR DEMONSTRATION***

- Drill

***FOR SMALL GROUPS***

- 2 Mason jars with lids
- 2 Pieces of 24" by ¼" tubing
- 5 oz. Vegetable oil or lamp oil
- 8 oz. 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
- *Enhanced Oil Recovery* worksheets, page 35-36 (for everyone)
- Map of *North American Oil and Gas Reservoirs*
- Drill
- Tongs
- Silicon sealant
- Safety glasses (for everyone)

## Time

- 45 minutes

## Preparation *for the demonstration*

- Fill the jar with marbles, stones, and pebbles.

Add 3-5 oz of lamp oil or vegetable 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*

- Drill 1/8" 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.

## ☑ Procedure

1. 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 lamp oil) is trapped within the pore space of rocks.
2. Gently shake the jar and show students how the oil is trapped in among the rocks. Pass the jar around and show the class the map of North American Oil and Gas Reservoirs.
3. Review *Oil and Gas Fields* in the Student Backgrounder. Explain to students that they are going to build their own model of an enhanced oil recovery system.
4. Divide students into small groups. Pass out the *Activity 6: Enhanced Oil Recovery Model* worksheet and go over the assignment. Remind students of the safety rules for handling dry ice. Circulate around the room and assist students as needed. *Note: This is a model of the enhanced oil recovery process. Students are using $CO_2$ in gas form to pump out the oil in their model reservoir. In actual practice, $CO_2$ is pressurized and pumped into the reservoir as a liquid. Geologic pressure keeps the $CO_2$ in liquid form.*

# Activity 7: Researching Regional Partnerships

## ✪ Objective

Students will focus on the North American regions that have partnered together to develop technology, infrastructure and regulations to implement large-scale $CO_2$ storage.

## Materials

- Computer and internet access
- *Research Planning* worksheets, pages 37-38, for each student
- Copies of *Activity 7: Research Regional Sequestration Partnerships* (pages 37-38) for each student

## Time

- Time will vary

## Preparation

- Familiarize yourself with the Carbon Sequestration Regional Partnerships at http://www.fossil.energy.gov/programs/sequestration/partnerships/index.html.

## ☑ Procedure

1. Divide the class into seven small groups. Assign each group to a different regional partnership and pass out the worksheets.

2. Groups look at the projects underway in their assigned partnership. The group chooses a project to learn about and create a multimedia presentation.

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 $CO_2$ source?

    How is the $CO_2$ being captured?

    Is/How $CO_2$ the being utilized?

    How is the $CO_2$ being stored?

    How much $CO_2$ has been stored?

    What lessons have been learned from this project?

    What is the next phase of the project?

4. Students present their multimedia projects to the class. As presentations are made, the other students take notes.

## Writing Extension

Each student picks 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.fossil.energy.gov/

**U.S. Environmental Protection Agency**
www.epa.gov

**U.S. Geological Survey**
www.usgs.gov

**United States Energy Association**
http://www.usea.org

**United States Energy Association $CO_2$ Capture and Storage News**
http://www.usea.org/CCS-news/CCS-news.asp

## Regional Sequestration Partnerships

**Big Sky Carbon Sequestration Partnership**
www.bigskyco2.org/

**Midwest Geological Sequestration Consortium**
www.sequestration.org/

**Midwest Regional Carbon Sequestration Partnership**
http://216.109.210.162/Default.aspx

**Plains $CO_2$ Reduction Partnership**
www.undeerc.org/pcor/

**Southeast Regional Sequestration Partnership**
www.secarbon.org/

**Southwest Partnership $CO_2$ Sequestration**
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. KIDS: 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.

Sources: NOAA and NWS

# Carbon Capture, Utilization and Storage

## Student Backgrounder

### Introduction

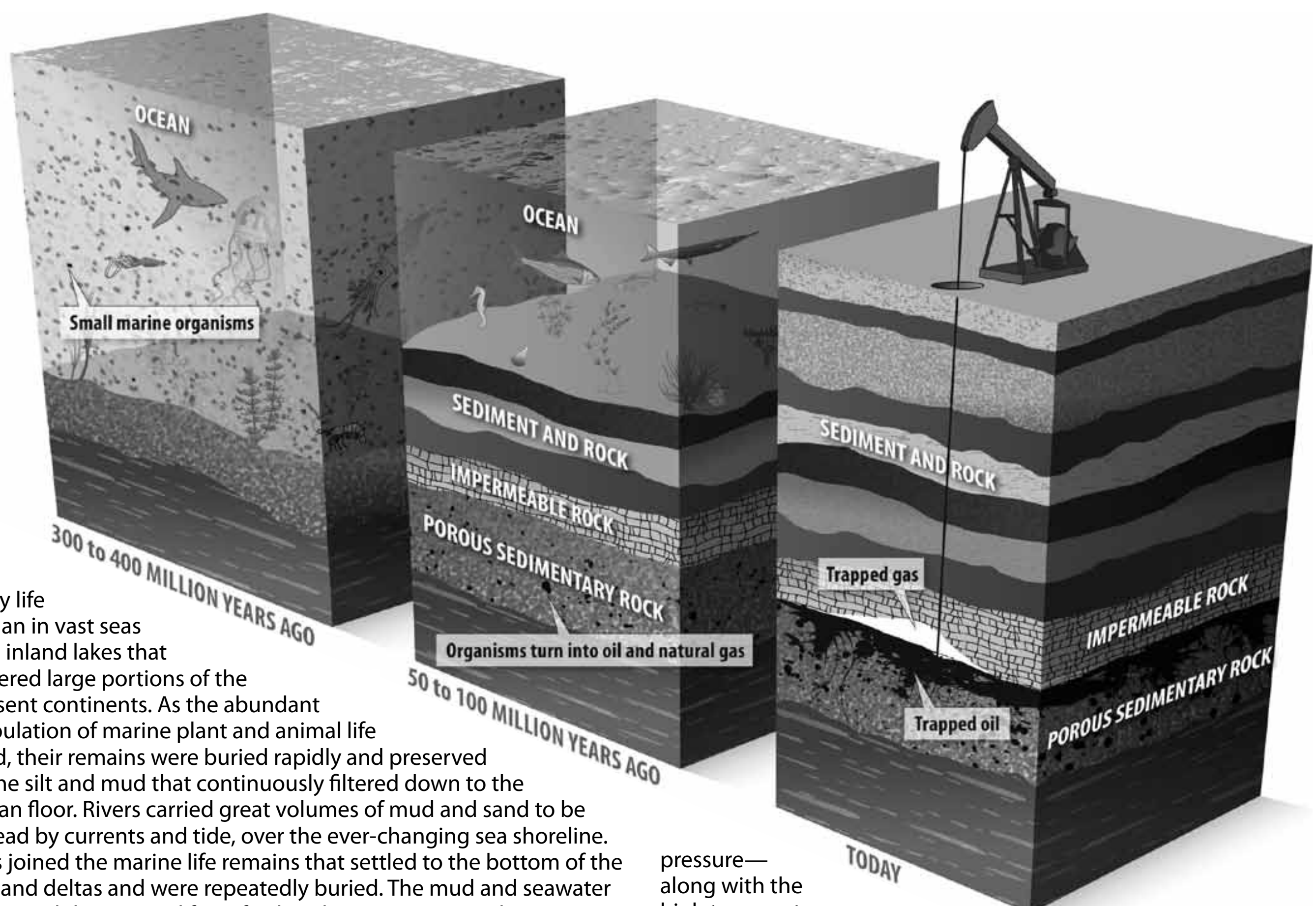
Most people in the United States use electricity on a daily basis. Electricity is not a primary source of energy because it has to be created. Rather, electricity is a secondary source of energy, or an energy carrier. We generate electricity from fossil fuels (coal, natural gas, oil), nuclear fuel, and renewables 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 nearly 70 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 ($CO_2$). These technological advances will stabilize and reduce the amount of $CO_2$ emissions, allowing for the continued use of domestic fossil fuel resources to meet our energy demand.

### Early Usage Fossil Fuels

Humans have been using coal and oil 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 of the surface of lakes and streams to use as medicine and to water-proof canoes. The Chinese were the

### Origins of Fossil fuels




Early life began in vast seas and inland lakes that covered large portions of the present continents. As the abundant population of marine plant and animal life died, their remains were buried rapidly and preserved in the silt and mud that continuously filtered down to the ocean floor. Rivers carried great volumes of mud and sand to be spread by currents and tide, over the ever-changing sea shoreline. This joined the marine life remains that settled to the bottom of the sea and deltas and were repeatedly buried. The mud and seawater protected the material from further decay. As more and more layers of organic material, sand, slit, clay, and lime accumulated and time passed, the weight of the overlying sediments exerted great pressure on the deeper sedimentary layers. With increasing weight of the accumulating sediments, the seafloors slowly sank, forming and preserving thick sequences of mud, sand, and carbonates. These eventually formed into sedimentary rocks. The tremendous pressure—along with the high temperature, bacterial action, and chemical reaction—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.

first to use coal found at or near land surface to smelt copper 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 iPod 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. Coal and natural gas are important sources for meeting the electricity demand in the United States.

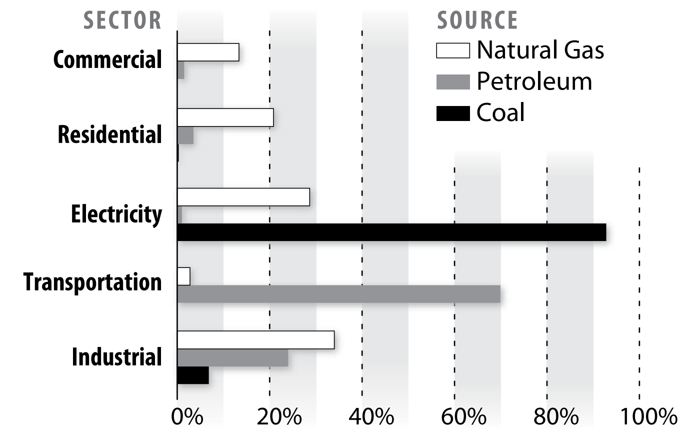
Coal power plants are base-load power plants. This means that they supply electricity 24 hours a day, seven days a week, usually at a constant rate. The only time these plants do not operate is when they must be taken off-line for maintenance. Bringing a coal power plant off-line takes time, and when 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 base-load plants and as peak-load 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. Base-load power cannot meet the demand, so peak-load power plants are brought on-line. Natural gas plants are good peak-load plants 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 where is 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.

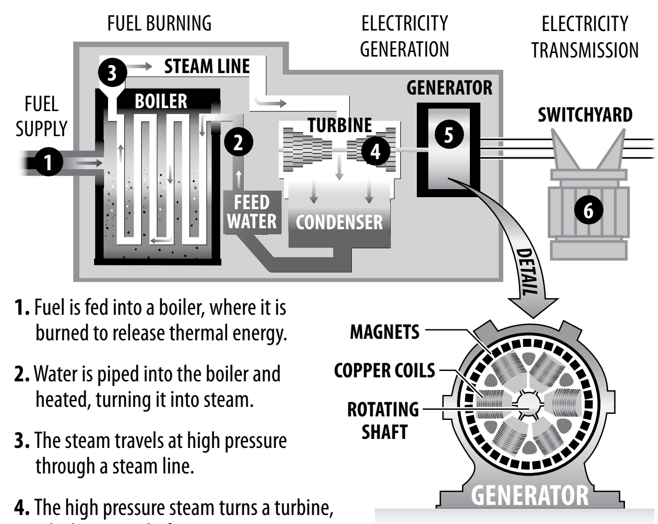
The steam does not stop once it reaches the turbine blades. From the turbine blades it continues traveling through pipes to a condenser where it is cooled into liquid water by passing it through pipes circulating over a large body of water or cooling towers. The water then returns to the boiler to be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

### Fossil Fuel Consumption By Sector, 2009




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.

## 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 ($SO_2$), carbon dioxide ($CO_2$), particulate matter (PM), and water vapor are all products of fossil fuel combustion. Regulations require power plants to reduce $NO_x$, $SO_2$, and PM through the use of scrubbers and flue-gas desulfurization.

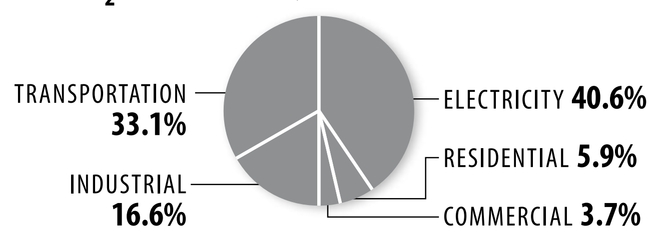
Naturally found in the atmosphere, $CO_2$ itself is not considered a pollutant. The $CO_2$ being released from burning fossil fuels was part of the atmosphere millions of years ago before being captured by plants and sea organisms. However, there has been increasing concern about the buildup of $CO_2$ concentrations in the atmosphere. International scientific consensus has concluded that the increase of $CO_2$ in the atmosphere is one of the causes of global climate change.

## Carbon Capture, Utilization and Storage

In 2009, over 30 billion metric tons of $CO_2$ were emitted worldwide related to fossil fuel energy consumption. Increasing levels of $CO_2$ 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 $CO_2$ before it enters the atmosphere, then to utilize it, or and 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 $CO_2$ entering the atmosphere.

While the transportation sector is responsible for about one-third of the country's $CO_2$ emissions, scientists believe the best use of CCUS technologies will be to focus on large stationary sources of $CO_2$ 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.

### U.S. $CO_2$ Emissions By Sector, 2009

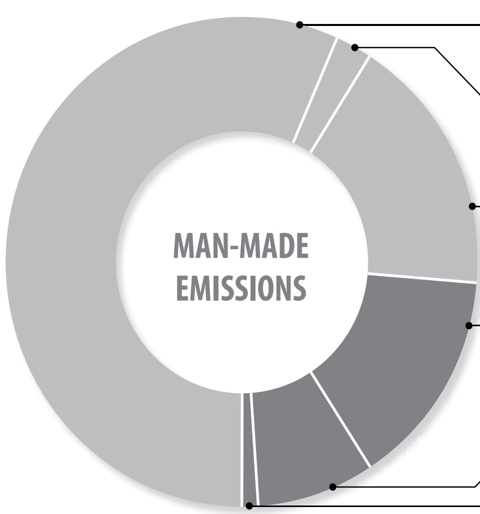



Data: Energy Information Administration

### Greenhouse Gases

Carbon dioxide accounts for more than 75 percent of all global greenhouse gas emissions, mainly due to the increased use of fossil fuels.
Since the Industrial Revolution, the concentration of all greenhouse gases has increased.

**GLOBAL GREENHOUSE GAS EMISSIONS**




| Global Greenhouse Gas Emissions | 2007 | Atmospheric Concentrations: Pre-Industrial (1750) | Atmospheric Concentrations: 2009 |
|---|---|---|---|
| CARBON DIOXIDE FROM FOSSIL FUELS | 56.6% | 278 parts per million | 384.8 parts per million |
| OTHER CARBON DIOXIDE | 2.8% | ALL CARBON DIOXIDE | |
| CARBON DIOXIDE FROM DEFORESTATION AND BIOMASS DECAY | 17.3% | | |
| METHANE | 14.3% | 0.72 parts per million | 1.8 parts per million |
| NITROUS OXIDE | 7.9% | 0.27 parts per million | 0.32 parts per million |
| F-GASES* | 1.1% | 0 parts per trillion | 84.5 parts per trillion |

* F-gases include HFCs, PFCs, and $SF_6$, which are used in many different industrial applications including as refrigerants, propellants, and tracer chemicals.
Data: U.S. Environmental Protection Agency, Intergovernmental Panel on Climate Change, Oak Ridge National Laboratory

# Four Main Parts to a CCUS system

1. The $CO_2$ gas is captured before or after fossil fuels are burned and compressed into a liquid form.
2. The liquid $CO_2$ is transported via pipeline to a utilization or geologic storage site.
3. At the utilization site, $CO_2$ is transformed into usable materials. Sometimes the utilization site is also the storage site.
4. At the storage site, the $CO_2$ is injected deep into the subsurface of the Earth where it is safely stored and monitored.

All parts of the CCUS system—$CO_2$ 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 $CO_2$ emitted into the atmosphere from stationary fossil fuel plants.

- **Step One: $CO_2$ Capture**

There are a number of different $CO_2$ 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 $CO_2$ and $H_2O$. 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 $CO_2$ making up only 4-15 percent of the end product.

Before entering the atmosphere, flue gas is treated by scrubber and flue gas sulferization 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 ($NH_3$). The $CO_2$ bonds with the chemicals creating a concentrated $CO_2$ solution. The solution is then heated to release the $CO_2$, 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 $CO_2$ for liquid and food preservation. Fertilizer manufacturing uses $CO_2$ as a feedstock. The construction industry uses $CO_2$ for concrete manufacturing. However, it has not been fully tested on a large scale and many questions remain.

Because there is a large capital 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.

## What is Carbon Capture, Utilization and Storage?

Carbon capture, utilization and storage is a process for reducing greenhouse gas emissions into the atmosphere by capturing $CO_2$ from stationary sources and using the $CO_2$ in new applications or storing the $CO_2$ in underground storage sites.

## Post-Combustion Capture

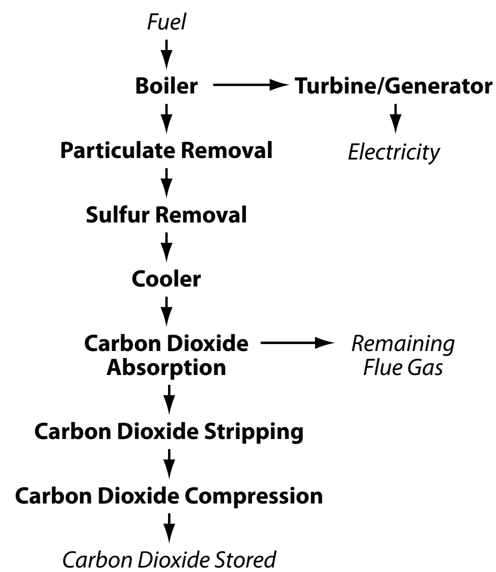
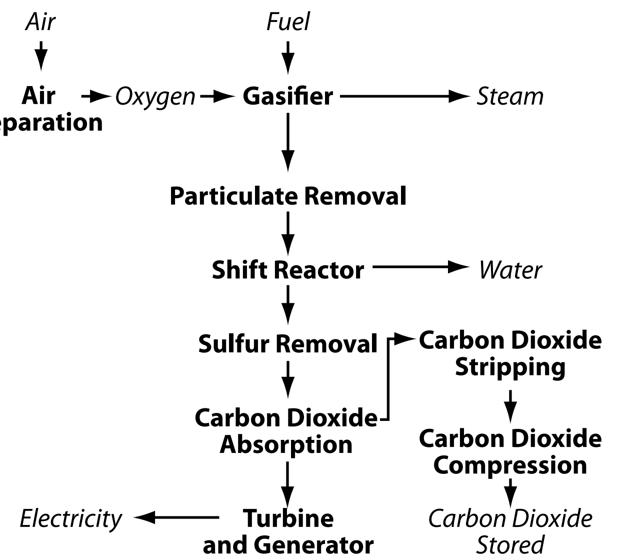



Image courtesy of Southeast Regional Carbon Sequestration Partnership

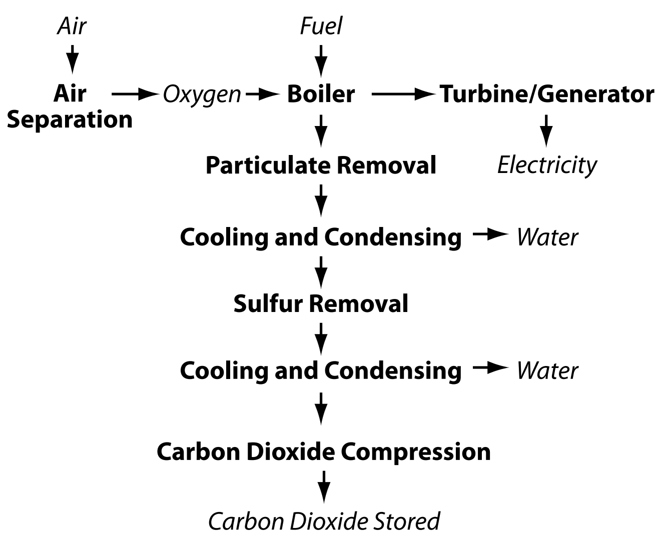
**The photo above shows the $CO_2$ capture unit at Alabama Power's Plant Barry. Using a post-combustion capture process developed by Mitsubishi Heavy Industries, $CO_2$ will be captured and then transported through 12 miles of pipeline to the injection site called the Paluxy Formation.**

**The Gulf Coastal region contains the largest capacity saline sinks in the United States. The Southeast Regional Carbon Sequestration Partnership is testing $CO_2$ injection and storage into the Paluxy Formation. Beginning in 2012, between 100,000 and 150,000 metric tons of $CO_2$ will be injected into the formation for a period of two to three years. This is the largest CCS facility for a coal-fired generating power plant to date.**

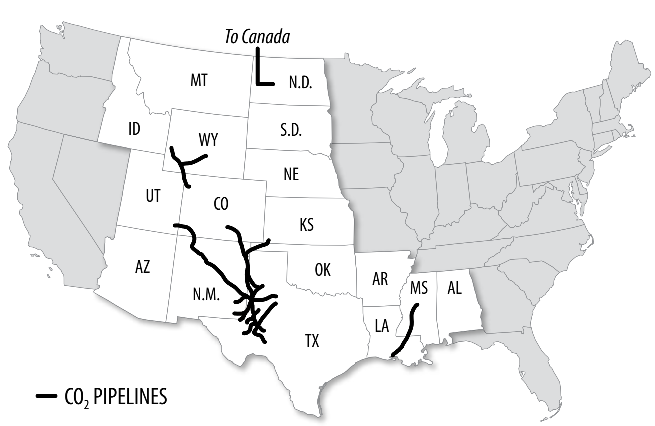
## Pre-Combustion Capture




## Oxy-Fuel Combustion Capture




## Existing $CO_2$ Pipelines




#### PRE-COMBUSTION CAPTURE

Capturing $CO_2$ with pre-combustion methods also uses existing technology. Prior to being burned, the fuel is combined with air or steam to divide the fuel into carbon monoxide (CO) and hydrogen. When coal is the fuel source, this 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 $CO_2$ and hydrogen. This creates a $CO_2$ concentration around 35-45 percent, which makes capturing the $CO_2$ 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 believe 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

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 $CO_2$ and water vapor. Concentrations of $CO_2$ 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 1300-1700 degrees Celsius (2300-3000° 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: $CO_2$ Transport

Once $CO_2$ is captured, the next step required is transportation to a storage site. In most cases, $CO_2$ 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 $CO_2$.

For distances up to 1,000 km (about 621 miles), pipelines are the preferred choice for $CO_2$ transport. In fact, $CO_2$ pipeline transport is not new. More than 5,800 km (3,600 miles) of pipeline already exist in the U.S. These pipelines primarily go to oil and gas fields where over 40 megatons of $CO_2$ ($MtCO_2$) each year are used for Enhanced Oil Recovery.

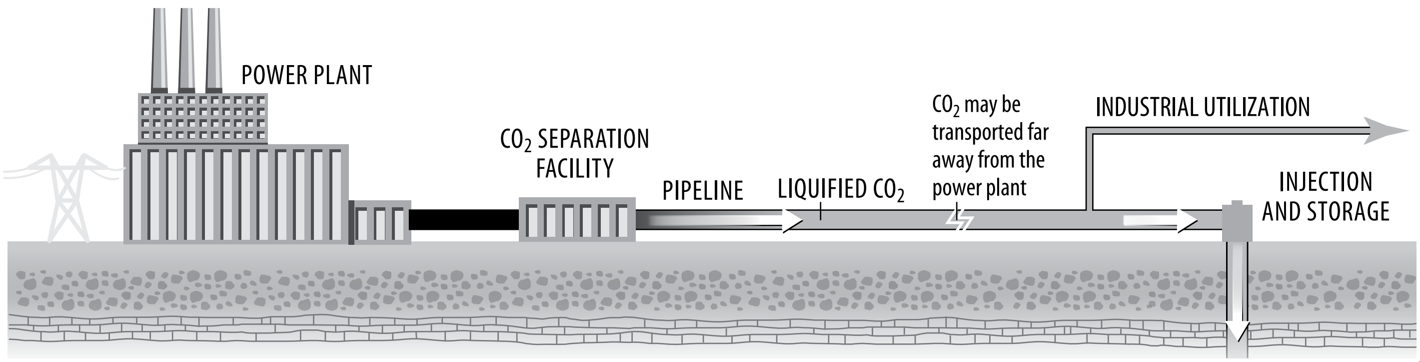
While pipelines are a proven technology in the oil and gas industry, there are challenges for developing a large pipeline infrastructure. Developing infrastructure will be costly. The location of pipelines will influence overall costs of CCUS. Engineers need to determine large-scale network requirements, and design pipelines and routes that will be safe through all types of terrain. Unlike oil and gas, $CO_2$ is non-explosive, non-hazardous, and non-toxic, and is not ignitable. Risks associated with $CO_2$ pipeline transport are expected to be less than those posed by oil and gas pipelines already in use.

Risks are low, but safeguards along a $CO_2$ 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 $CO_2$ releases should they arise. A small $CO_2$ leak would self seal as it froze and not pose an immediate danger. In concentrations of seven to ten percent (by volume in air), $CO_2$ is dangerous to human health. When $CO_2$ is released from a pipeline it is denser than air and stays along the ground settling into low spots. In most conditions, the $CO_2$ would quickly transform into a gas and be diluted and dispersed with the wind.

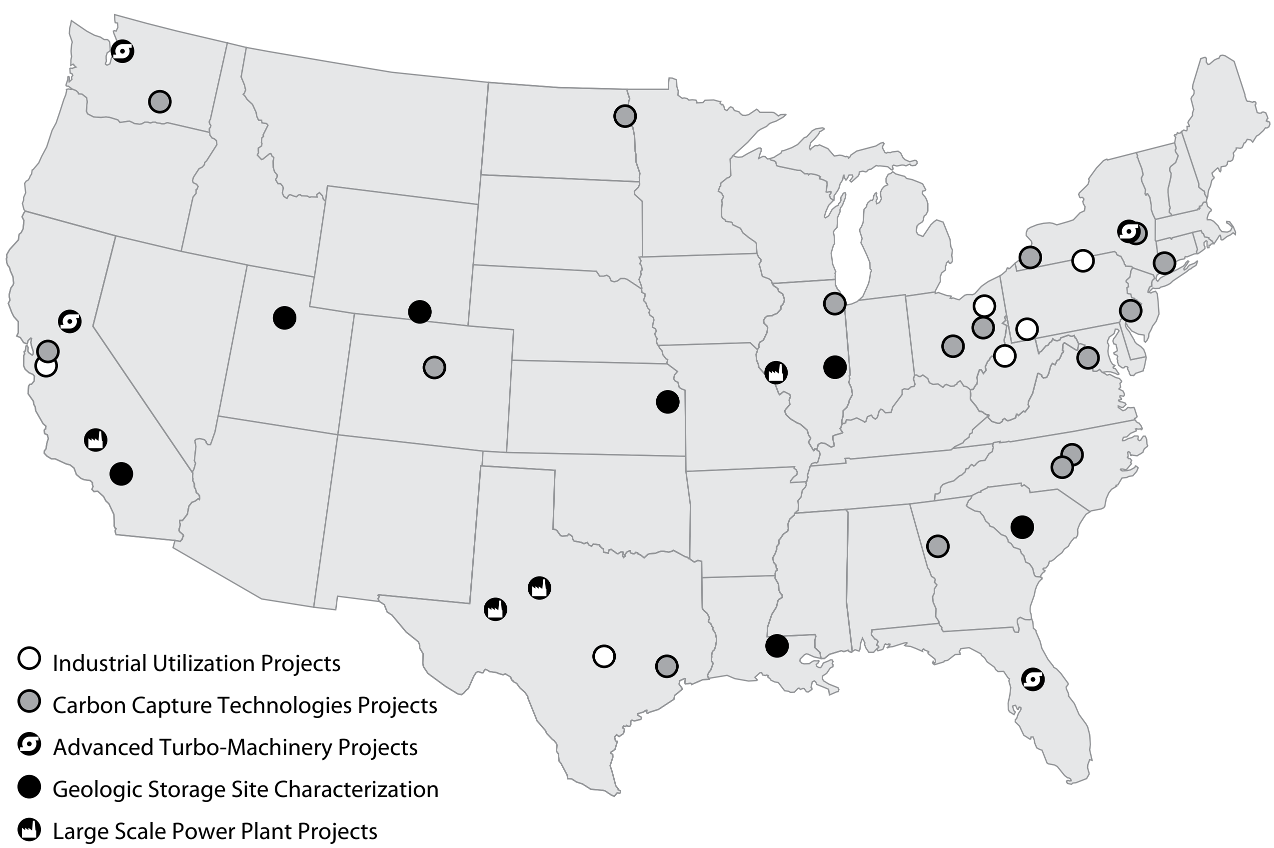
The food and beverage industry currently uses tanker trunks to transport $CO_2$. However, trucks and rail cars will be uneconomical for large scale $CO_2$ transportation. In the U.S., pipelines are expected to transport all of the captured $CO_2$. In other parts of the world, engineers are considering the possibility of using ships for transporting smaller amounts of $CO_2$.

## 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 Underway in the U.S.




Data: U.S. Department of Energy and Massachusetts Institute of Technology Carbon Capture and Sequestration Technologies Program

## ▪ Step Three: Utilization

One way to mitigate the amount of $CO_2$ entering the atmosphere is to find other uses for the gas. For a long time $CO_2$ has been used to carbonate beverages, as the active ingredient in fire extinguishers, and in refrigeration. Most current and potential uses of $CO_2$ tend to be on a small scale however, and they also typically emit the $CO_2$ into the atmosphere after its use. Scientists are studying ways that $CO_2$ can be used in larger scale applications, and in ways that do not produce more $CO_2$ than what is trying to be saved from entering the atmosphere originally. There are four main $CO_2$ 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 $CO_2$ 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, $CO_2$ is injected into the wells. Some of the $CO_2$ 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 48 metric tons of $CO_2$ are injected underground each year for EOR, but the source of $CO_2$ typically comes from naturally occurring geologic formations. Today, most EOR operations are onshore in West Texas. Using $CO_2$ for EOR has the advantage of having revenue associated with the $CO_2$. 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 $CO_2$. Scientists are working to develop a process that consumes $CO_2$ 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 $CO_2$ 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 $CO_2$ to produce minerals such as calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). These minerals are highly stable and there is little concern that the $CO_2$ 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 $CO_2$

Carbon dioxide is currently used in a variety of ways. Most of these materials currently utilize naturally occurring $CO_2$. Research is underway on how to use $CO_2$ captured from stationary sources in some of these products.

**BIOLOGICAL CONVERSION**
- Fuels
- Food

**EXTRACTANT**
- Flavors/Fragrances
- Decaffeination

**MINERALIZATION**
- Carbonates

**CHEMICALS**
- Liquid Fuels
- Fertilizer

**REFRIGERANT**
- Refrigeration
- Dry Ice

**INERTING AGENT**
- Blanket Products
- Protect Carbon Powder
- Shield gas in welding

**FIRE SUPPRESSION**
- Fire Extinguishers

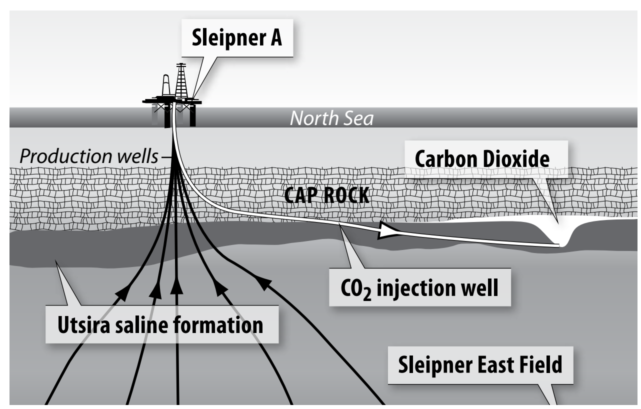
**PLASTICS**
- Polycarbonate
- Polymers

**ENHANCED HYDROCARBON RECOVERY**
- Oil
- Gas

**FOOD/PRODUCTS**
- Carbonated Beverages

**MISCELLANEOUS**
- Injected into metal castings
- Added to medical $O_2$ 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 $CO_2$ from natural gas production since 1996. Captured directly from natural gas production, $CO_2$ is stored 2,625 feet (800 m) below the seabed. Over 11 millions tons of $CO_2$ have been stored inside the Utsira formation since the project began.**

- **Step Four: Geologic Storage**

Determining a suitable location for $CO_2$ storage depends on a thorough site assessment. Sites are evaluated for their storage capacity, injectivity rates, and abilities to contain $CO_2$. Using a variety of tools, geologists study the area to make sure the reservoir is capable of containing the $CO_2$ indefinitely.

$CO_2$ will be injected as a liquid into porous rock formations that hold, or once held, fluids. Injecting $CO_2$ deeper than 800 meters will allow the natural pressure of the Earth to keep $CO_2$ in a liquid state, which makes it less likely to migrate out of the formation

Currently, there are three potential reservoirs for storing $CO_2$ 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.

### DEPLETED OIL AND GAS FIELDS

Using depleted oil and gas reservoirs without enhanced oil recover is another option for $CO_2$ 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 $CO_2$ into the reservoir. If not properly capped, however, the same wells may be a conduit for $CO_2$ release. Usually these reservoirs are quite a distance from the $CO_2$ source so constructing pipelines to connect the source to the reservoir could be costly.

### DEEP SALINE FORMATIONS

The largest potential capacity for $CO_2$ 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 $CO_2$ than oil and gas reservoirs.

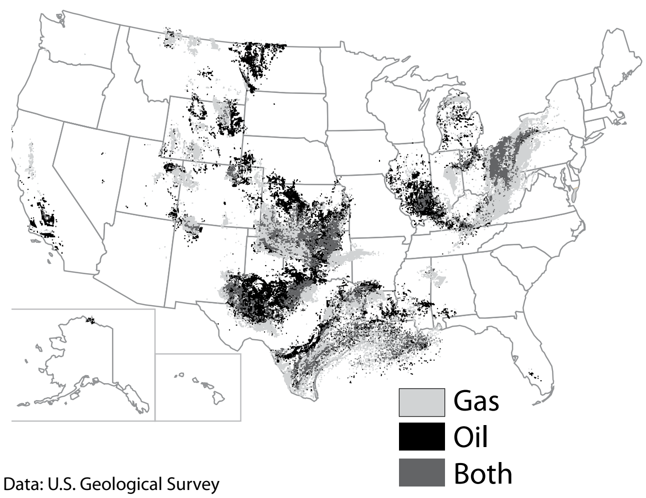
When injected into the brine, $CO_2$ is expected to eventually dissolve and later mineralize to become part of the rock formation. Since 1996, the Sleipner Project in the North Sea has been utilizing this technology. Over 1 $MtCO_2$ is stored each year into the Utsina formation, a sandstone reservoir below the sea that is 200-250 m (650-820 ft) thick that contains saline fluids. There are no signs that the $CO_2$ has leaked out from the formation, and researchers believe that the $CO_2$ will dissolve into the saline.

## 2010 Carbon Sequestration Atlas Estimates (Million Metric Tons)

| | |
|---|---|
| Oil and Gas Fields | 134,580 |
| Deep Saline Formations | 1,614,520 - 20,162,540 |
| Unmineable Coal Seams | 59,460 - 117,810 |

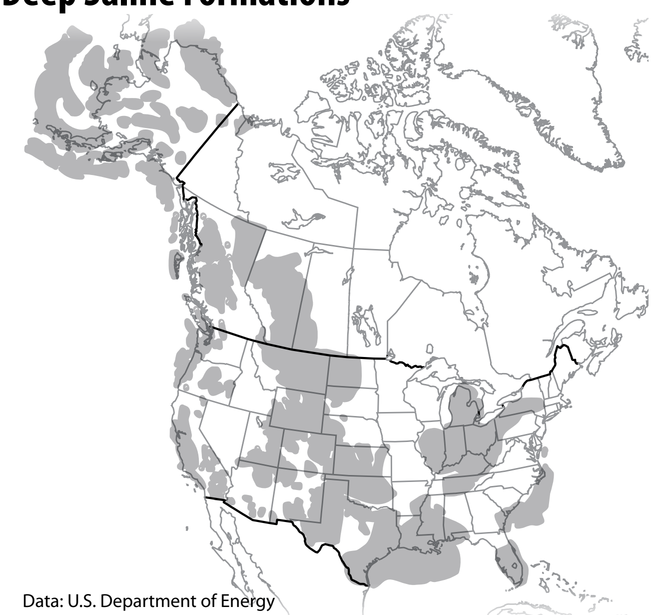
Source: Department of Energy

## Oil and Gas Production and Exploration




Data: U.S. Geological Survey

## Deep Saline Formations



Data: U.S. Department of Energy

### UNMINEABLE COAL SEAMS

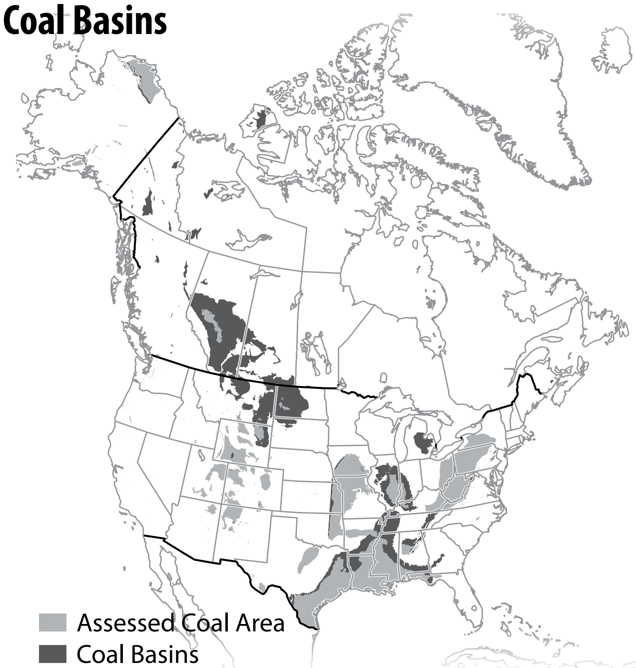
The U.S. has the largest recoverable coal reserves in the world. Even so, with today's technology 90 percent of coal resources remain unmineable. The U.S. Department of Energy (DOE) estimates unmineable coal seams in the U.S. have more potential capacity for $CO_2$ storage than oil and gas fields.

Methane is a gas commonly found trapped in coal seams. $CO_2$ will adhere to coal more tightly than methane does. For every methane molecule released, three to thirteen $CO_2$ molecules can be adsorbed to the coal. This means $CO_2$ 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 $CO_2$, but there still is a net storage of $CO_2$ in the unmineable coal seam.

Whether storing $CO_2$ 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 $CO_2$ point sources, which would reduce transportation distances.

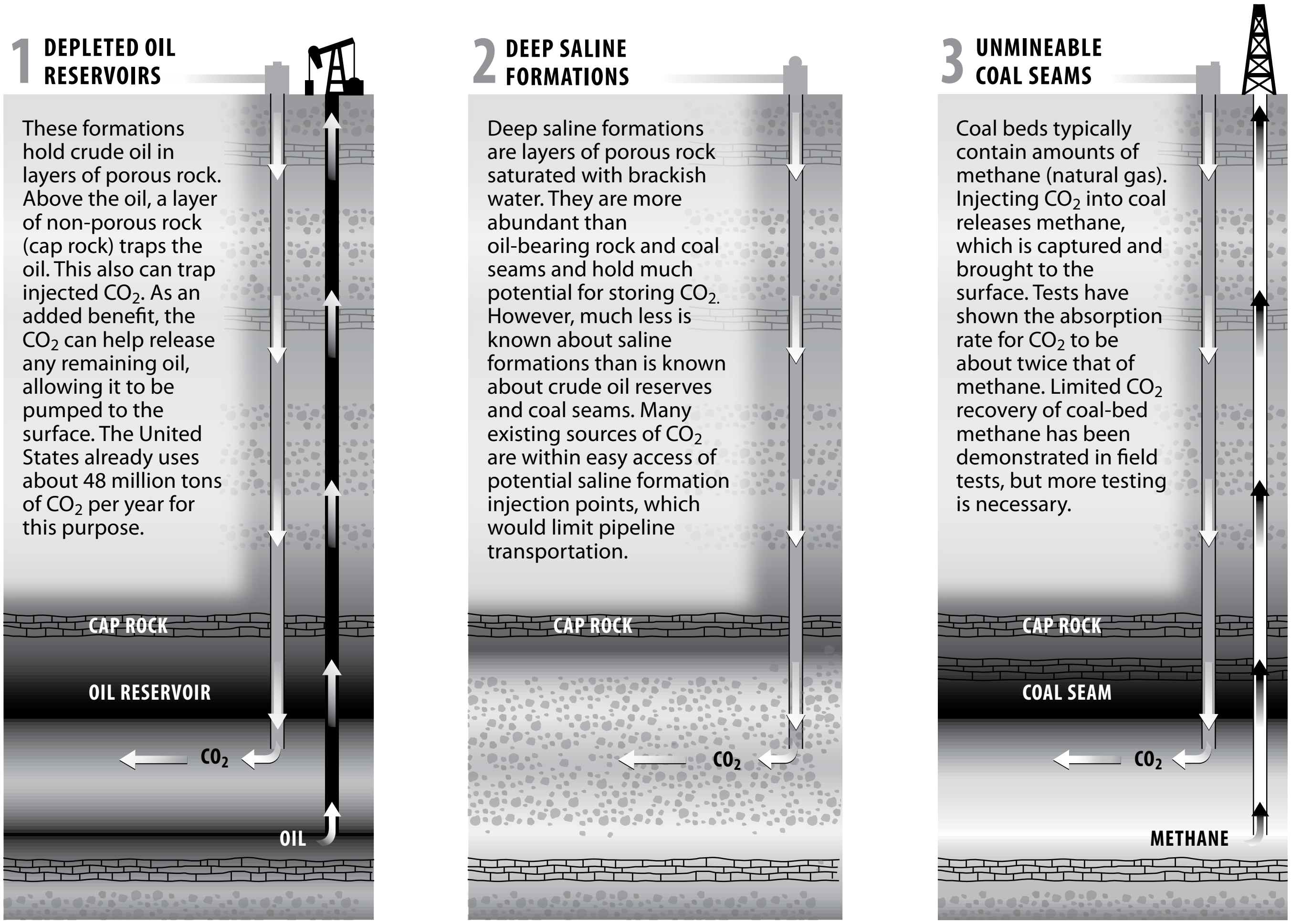
Geologic storage solutions are further along in development than other storage options. Yet studies, computer simulations, and physical research are being conducted on mineral carbonation.

## Coal Basins




Data: U.S. Department of Energy

## Strategies For Geologic Storage Of Carbon Dioxide

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### BASALT FORMATIONS

Given thousands, or millions, of years $CO_2$ will naturally react to its surroundings and convert into $CaCO_3$, or limestone. In this state, $CO_2$ is solid and stable. It no longer cycles in and out of the atmosphere. Scientists are trying to speed up this process by combining $CO_2$ with minerals such as olivine or serpentine creating a solid, and then storing the new solid in a repository.

In order to transform $CO_2$ 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 $CO_2$ in the process. Large amounts of silicate oxide materials are needed, as much as 3.7 metric tons to store one ton of $CO_2$.

After the reactant minerals are ready they are piped into a concentrated $CO_2$ 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 $CO_2$ in situ, or "in place." Injecting $CO_2$ directly into basalt formations would allow the $CO_2$ 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 $CO_2$. Research is beginning in the flood basalts of the Columbia River Plateau in the Pacific Northwest.

**Basalt Formations**

Data: Idaho National Laboratory

## CCUS Costs

In order to mitigate climate change, CCUS technologies need to be a part of the solution. Utilizing or capturing $CO_2$ offers the most viable way to generate electricity at the current level, with resources we have readily available, and significantly reduce the $CO_2$ impact on the environment. There will be other environmental impacts and economic costs for pursuing CCUS technologies.

Capturing and compressing $CO_2$ 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 $CO_2$. 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 $CO_2$ 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 offline undergoing the retrofit. Overall, the Department of Energy 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.

**U.S. Average Levelized Costs ($/Megawatt-hour) for Plants Entering Service in 2016**

| | |
|---|---|
| Conventional Coal | $94.80 |
| Advanced Coal with CCUS | $109.40 |
| Natural Gas-fired | |
| Conventional Combined Cycle | $66.10 |
| Advanced CC with CCUS | $89.30 |
| Advanced Nuclear | $113.90 |
| Wind | $97.00 |
| Wind – Offshore | $243.20 |
| Solar PV | $210.70 |
| Solar Thermal | $311.80 |
| Geothermal | $101.70 |
| Biomass | $112.50 |
| Hydropower | $86.40 |

Data: Annual Energy Outlook 2011, EIA

The use of $CO_2$ for EOR is already occurring, and the demand for $CO_2$ is higher than the supply. Potential for $CO_2$ 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 $CO_2$. In the long term, however, the capacity of this reservoir is relatively small and few companies will be able to take advantage of selling $CO_2$ 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 will 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 $CO_2$ emissions. Because the costs of new CCUS technologies are not recoverable in electric rates (e.g., customer's electric bills) until $CO_2$ 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 $CO_2$ emissions. If reducing $CO_2$ 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 $CO_2$ emissions while adding less than 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.

Currently there are 5,800 km (3,600 miles) of $CO_2$ pipelines in the United States, the first of which was the Canyon Reef Carriers Pipeline, which began operation in 1972. The Canyon Reef Carrier Pipeline is located in Surry County, TX and was built to bring $CO_2$ from Sheill Oil Co. gas processing plants to the Texas Val Verde Basin.

$CO_2$ pipelines, as with natural gas and petroleum pipelines, are regulated by the U.S. Department of Transportation's Office of Pipeline Safety. While $CO_2$ is a non-flammable gas, $CO_2$ 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 $CO_2$ pipelines. None of these incidents resulted in injuries to people. Transporting $CO_2$ by pipeline is a safe transportation option.

Selecting an appropriate geologic storage site is an important factor in reducing risks associated with $CO_2$ storage. A suitable site will contain porous rocks that will trap the $CO_2$. Natural mechanisms in the porous rock will contain the $CO_2$ within its pore spaces. When $CO_2$ interacts with the brine (salt water) found in the permeable rock, the $CO_2$ will eventually dissolve. The solution becomes a weak acid, which over time forms new minerals binding the $CO_2$ to rocks permanently.

The permeable rock space where $CO_2$ is stored is capped by an impermeable caprock. This restricts any upward movement of the $CO_2$. In addition, the reservoirs and wells are closely monitored. Scientists use 4D seismic surveys with temperature and pressure sensors to monitor and map the $CO_2$ 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 carbon capture, utilization and storage at the commercial scale. Incorporating additional CCUS technology into existing plants and new designs will be expensive. Infrastructure for transporting $CO_2$ needs to be built. Appropriate geologic formations for storage need to be identified. Laws regulating who is responsible when $CO_2$ passes through multiple states, and for the $CO_2$ 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.

### Average Price of Electricity by State, 2009

| LEAST EXPENSIVE | CENTS/kWh | MOST EXPENSIVE | CENTS/kWh |
|---|---|---|---|
| Idaho | 7.99 | Hawaii | 28.10 |
| Washington | 8.04 | Connecticut | 19.25 |
| North Dakota | 8.13 | New York | 18.74 |
| Kentucky | 8.57 | New Jersey | 16.57 |
| Utah | 8.71 | New Hampshire | 16.32 |
| Wyoming | 8.77 | Alaska | 16.26 |
| West Virginia | 8.79 | Rhode Island | 15.92 |
| Arkansas | 8.86 | Maine | 15.71 |
| Oregon | 8.87 | Vermont | 15.57 |
| Nebraska | 8.94 | California | 14.75 |

Data: Energy Information Administration

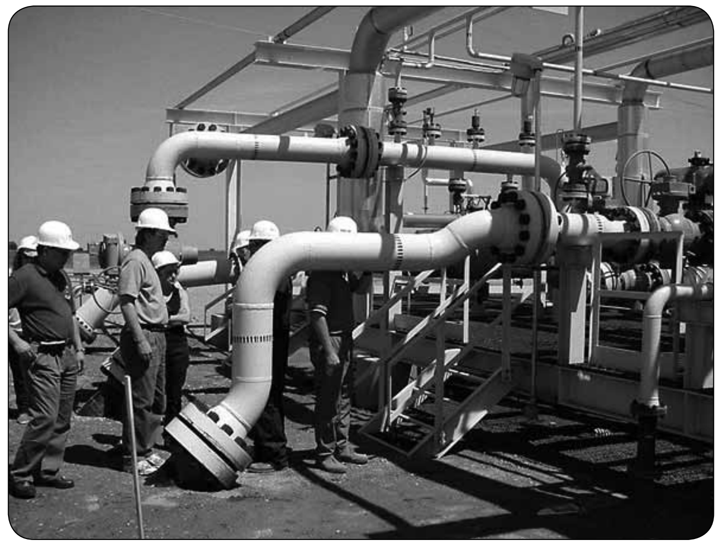


Image courtesy of Petroleum Technology Research Centre

**This pipeline at Cenovous' oil field in Weyburn, Saskatchewan, Canada, has transported $CO_2$ 330 km from Beulah, ND. The $CO_2$ will be used for enhanced oil recovery, and ultimately stored underground in the depleted oil reservoir.**

Managing anthropogenic, man-made, sources of $CO_2$ 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 $CO_2$ 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 $CO_2$ by the year 2030 without significant $CO_2$ mitigation.

It will take many different $CO_2$ management styles to reduce $CO_2$ 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 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. |
| **adsorption** | Taking up and holding (a gas, liquid, or dissolved substance) in a thin layer of molecules on the surface of a solid substance. |
| **anthropogenic** | Made or generated by a human or caused by human activity. The term is 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. |
| **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 cycle** | All carbon sinks and exchanges of carbon from one sink to another by various chemical, physical, geological, and biological processes. Also see **carbon sink** below. |
| **carbon dioxide ($CO_2$)** | A colorless, odorless, non-poisonous gas that is a normal part of Earth's atmosphere. Carbon dioxide is a product of fossil-fuel combustion as well as other processes. It is 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 intensity** | The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels. |
| **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 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. In some cases, "climate change" has been used synonymously with the term "global warming;" scientists, however, tend to use the term in a wider sense inclusive of natural changes in climate, including climatic cooling. |
| **coal** | A readily combustible black or brownish-black rock whose composition, including inherent moisture, consists of more than 50 percent by weight and more than 70 percent by volume of carbonaceous material. It is 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. The basic process 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. The gas can be used as a fuel or processed further and concentrated into chemical or liquid fuel. |
| **combined cycle** | An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. This process increases the efficiency of the electric generating unit. |
| **combined cycle unit** | An electric generating unit that consists of one or more combustion turbines and one or more boilers with a portion of the required energy input to the boiler(s) provided by the exhaust gas of the combustion turbine(s). |
| **combustion** | Chemical oxidation accompanied by the generation of light and heat. |
| **emissions** | Anthropogenic releases of gases to the atmosphere. In the context of global climate change, they consist of radiatively important greenhouse gases (e.g., the release of carbon dioxide during fuel combustion). |
| **enhanced fuel recovery** | The recovery of oil and gas from reservoirs using means other than using natural reservoir pressure. Enhanced fuel recovery 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. These are gases 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 milions of years. |
| **fossil fuel plant** | A plant using coal, petroleum, or natural gas as its source of energy. |
| **gas to liquids (GTL)** | A process that combines the carbon and hydrogen elements in natural gas molecules to make synthetic liquid petroleum products, such as diesel fuel. |
| **gas turbine plant** | A plant in which the prime mover is a gas turbine. A gas turbine consists typically of an axial-flow air compressor and one or more combustion chambers where liquid or gaseous fuel is burned and the hot gases are passed to the turbine and where the hot gases expand drive the generator and are then used to run the compressor. |
| **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 maintains 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** | A broadly defined class of liquid hydrocarbon mixtures. Included are crude oil, lease condensate, unfinished oils, 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 natural gas (SNG)** | A manufactured product, chemically similar in most respects to natural gas, resulting from the conversion or reforming of hydrocarbons that may easily be substituted for or interchanged with pipeline-quality natural gas. Also referred to as substitute natural gas. |
| **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 Dioxide and Carbon Capture, Utilization and Storage KWL Chart

| What I Think I Know | What I Want to Know | What I Learned |
|---|---|---|
| | | |

# Activity 1: Modeling Combustion

## Materials

- 4 2″ Spheres (oxygen)
- 4 1″ Spheres (hydrogen)
- 1 1 ½″ Spheres (carbon)
- 16 Toothpicks

## Procedure

1. Use the spheres to build methane, $CH_4$. Draw the model below:

2. Build two oxygen ($O_2$) molecules. Draw the model below:

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

**$CH_4 + 2\ O_2 \longrightarrow$ ___________**

Draw the products of combustion below:

# Activity 2: 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

1. If you drive 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 to school?

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

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

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

## Conclusions

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

# Activity 3: Properties of $CO_2$

**What are the properties of $CO_2$ as a gas? Record your observations below.**

# Activity 4: 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:**

$$\frac{\textbf{Known Value - Experimental Value}}{\textbf{Known Value}} \times 100$$

## Conclusion

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?

# Activity 5: Exploring Porosity

## Question

How does the size of material pieces affect porosity?

## Hypothesis

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

## Materials

- 1 Bag of very small rocks
- 1 Bag of small gravel
- 1 Bag of medium gravel
- 1 – 100 mL Graduated cylinder
- 3 – 500 mL Beakers
- Water, dyed with food coloring
- Safety glasses

## Procedure

1. Fill one beaker to the 350 mL mark with medium gravel, fill a second beaker with 350 mL of small gravel, and fill the third beaker with 350 mL of very small rocks.
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:

$$\textbf{Porosity} = \frac{\textbf{volume of water}}{\textbf{volume of material}} \textbf{ x 100.}$$

## Data

| MATERIAL | WATER HELD (ML) |
|---|---|
| Beaker 1 – Medium Gravel | |
| Beaker 2 – Small Gravel | |
| Beaker 3 – Very Small Rocks | |

## Conclusion

Did the results allow you to confirm or reject your hypothesis? How does porosity affect the ability of a material to contain carbon dioxide?

# Activity 6: Enhanced Hydrocarbon Recovery Model

## 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

- 2 Mason jars
- 1 Mason jar lid with two 1/4" holes
- 1 Mason jar lid with one 1/4" 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
- 3-5 oz. Vegetable oil or lamp oil
- 8 oz. Water
- 1 Dark color of food dye
- Silicon sealant
- Tongs
- Gloves
- Safety glasses
- *Dry Ice Safety*

## Procedure

1. Review *Dry Ice Safety* rules.
2. Fill one mason jar with marbles, rocks, and sand.
3. Add 5 oz. of vegetable oil. This represents crude oil.
4. Fill the rest of the jar with water.
5. Put the lid with two holes on the jar and secure tightly.
6. Cover the holes in the lid and gently shake the jar.
7. Put one piece of tube all of the way down into the bottom of the filled mason jar. Secure the tube. Place the open end of this tube into the water bottle, which will be your reservoir jar.
8. Using tongs, put a piece of dry ice into the second mason jar. Put the lid with one hole on and secure tightly.
9. Put the second piece of tubing into the hole in the lid of the dry ice jar. Put the other end of the tube about two inches down into your reservoir jar.

## Observations

Record observations in your science notebook.

## Conclusions

Did the results allow you to confirm or reject your hypothesis? How does carbon dioxide allow for enhanced oil recovery? What are some of the benefits? What are some of the challenges?

# Activity 6: Enhanced Hydrocarbon Recovery Model

## Observations

Draw a diagram of your reservoir model. Describe what is happening. Where is the $CO_2$ going? Where is the oil going? How much oil were you able to recover?

## Conclusion

How does carbon dioxide allow for enhanced hydrocarbon recovery? What are some of the benefits? What are some of the challenges?

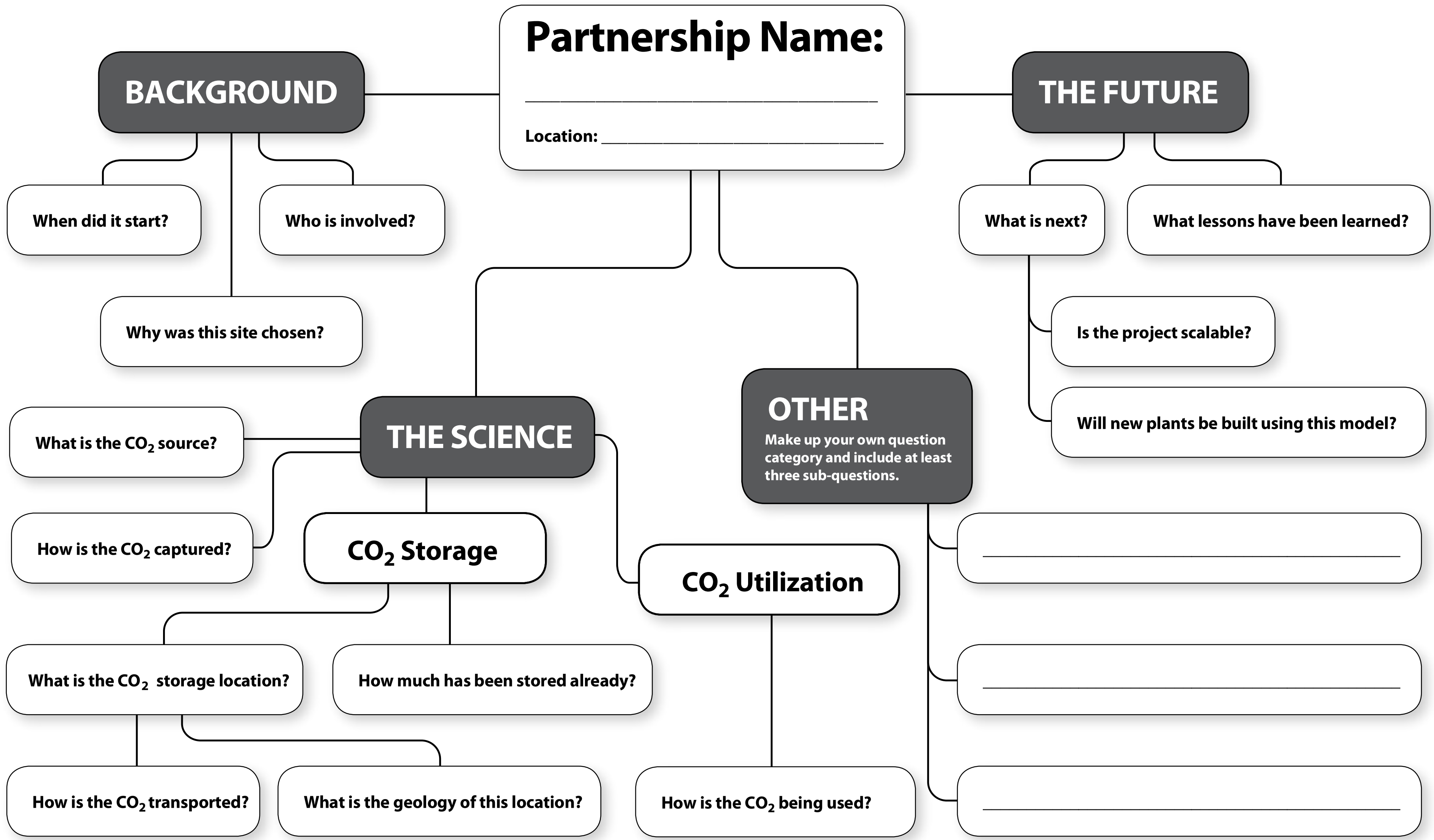
# Activity 7: Research Regional Sequestration Partnerships

**Name of partnership:**

**What states and/or provinces are part of the partnership?**

**What research is being done by the partnership?**

**Choose one research project to study more in depth and create a multimedia presentation to share with your class. Use the mind map on the next page to help focus your presentation.**



Partnership Name:
Location:
BACKGROUND
When did it start?
Who is involved?
Why was this site chosen?
THE FUTURE
What is next?
What lessons have been learned?
Is the project scalable?
Will new plants be built using this model?
THE SCIENCE
What is the $CO_2$ source?
How is the $CO_2$ captured?
$CO_2$ Storage
What is the $CO_2$ storage location?
How much has been stored already?
How is the $CO_2$ transported?
What is the geology of this location?
$CO_2$ Utilization
How is the $CO_2$ being used?
OTHER
Make up your own question category and include at least three sub-questions.

# Carbon Capture, Utilization and Storage Evaluation Form

SYNTHESIS

**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**
P.O. Box 10101
Manassas, VA 20108
FAX: 1-800-847-1820

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National Ocean Industries Association
National Renewable Energy Laboratory
Nebraska Public Power District
New Mexico Oil Corporation
New Mexico Landman's Association
New Orleans Solar Schools Initiative
New York Power Authority
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Offshore Energy Center
Offshore Technology Conference
Ohio Energy Project
Pacific Gas and Electric Company
PECO
Petroleum Equipment Suppliers Association
PNM
Puerto Rico Energy Affairs Administration
Puget Sound Energy
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Schneider Electric
Science Museum of Virginia
C.T. Seaver Trust
Shell
Snohomish County Public Utility District–WA
Society of Petroleum Engineers
SolarWorld USA
David Sorenson
Southern Company
Southern LNG
Southwest Gas
Space Sciences Laboratory–University of California Berkeley
Tennessee Department of Economic and Community Development–Energy Division
Tennessee Valley Authority
Toyota
TXU Energy
United States Energy Association
University of Nevada–Las Vegas, NV
U.S. Department of Energy
U.S. Department of Energy–Hydrogen Program
U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy–Office of Fossil Energy
U.S. Department of Energy–Wind for Schools
U.S. Department of Energy–Wind Powering America
U.S. Department of the Interior–Bureau of Land Management
U.S. Department of the Interior–Bureau of Ocean Energy Management, Regulation and Enforcement
U.S. Energy Information Administration
U.S. Environmental Protection Agency
Van Ness Feldman
Virgin Islands Energy Office
Virginia Department of Education
Virginia Department of Mines, Minerals and Energy
Walmart Foundation
Washington and Lee University
Western Kentucky Science Alliance
W. Plack Carr Company
Yates Petroleum Corporation