CO_2 – Too Much of a Good Thing?

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TOPIC: CARBON DIOXIDE

MODULE TOPIC

Carbon Dioxide – Too Much of a Good Thing?

OVERVIEW

The objectives of these activities are for students to better understand:

1. how CO_2 is formed in the combustion of hydrocarbon molecules,
2. the various ways humans produce CO_2 in daily activities,
3. why CO_2 causes heat to be trapped in the atmosphere,
4. the properties of CO_2 and its health and safety risks, and
5. how geologic storage of CO_2 can work to reduce emissions.

BACKGROUND INFORMATION

Did You Know?

Many scientists are concerned about the large amount of CO_2 going into the atmosphere from the burning of fossil fuels. The main concern is that CO_2 is a greenhouse gas. Scientists know that these greenhouse gases (gases such as CO_2, methane and water vapor) contribute to warming our atmosphere, and therefore, the planet. Some students, while they understand that burning gasoline in their car results in CO_2 emissions, incorrectly think that electricity in general is a clean form of energy. This misconception mainly stems from the fact that students do not understand the difference between a primary energy source (e.g., oil, coal) and a secondary energy source (e.g., electricity).

Primary energy is energy found in nature that has not been subjected to any conversion or transformation process. It is energy contained in raw fuels as well as other forms of energy. It includes non-renewable energy and renewable energy.

Primary energy sources include:

1. Biomass – energy from biological material of living, or recently living organisms, such as wood, waste, (hydrogen) gas, and alcohol fuels; often accessed through burning
2. Fossil fuels – energy of the sun stored over millions of years by plants and animals, then trapped under sediments and converted by underground pressure and heat to coal, oil or gas
3. Geothermal power - heat trapped inside the earth when it was being formed plus heat produced within the earth by ongoing radioactive decay
4. Hydro power - power that is derived from the force or energy of moving water, especially falling water (rivers, dams, etc.)
5. Nuclear fuels – fuels produced in astrophysical events, before the solar system was born, as naturally occurring radioactive isotopes
6. Solar energy – energy of heat and light radiated through space, coming from the sun
7. Tidal power - energy associated with ocean water flow due to tides

8. Wave power - energy from ocean surface waves, captured to do useful work
9. Wind power – energy from weather phenomena derived from uneven heating of the earth by the sun

Primary energies are transformed in energy conversion processes to more convenient forms of energy, such as electrical energy, refined fuels, or synthetic fuels such as hydrogen fuel. Secondary energy is the term used for an energy form which has been transformed from another one. Electricity is the most common example, being transformed from such primary sources as coal, natural gas, solar and wind.

Secondary sources are important because they are frequently easier to use than the primary sources from which they are derived. Conservation of energy guarantees that we will never be able to devise a means to produce more secondary energy than the amount of primary energy that was required to make it. Our ability to use energy will always be strictly limited by the availability of primary energy sources.

Source: http://en.wikipedia.org/wiki/Primary_energy, http://weltycenter.org/resource-center/, accessed 11/24/2015

Did you know that coal is the source for a little under half of all electricity generated in the U.S.? Coal-fired power plants are common in many areas of the country. Natural gas is the source for about a quarter of U.S. electricity, and nuclear supplies about a fifth of the nation's needs. Hydroelectric and other renewables together account for about a tenth of U.S. electricity generation by source.

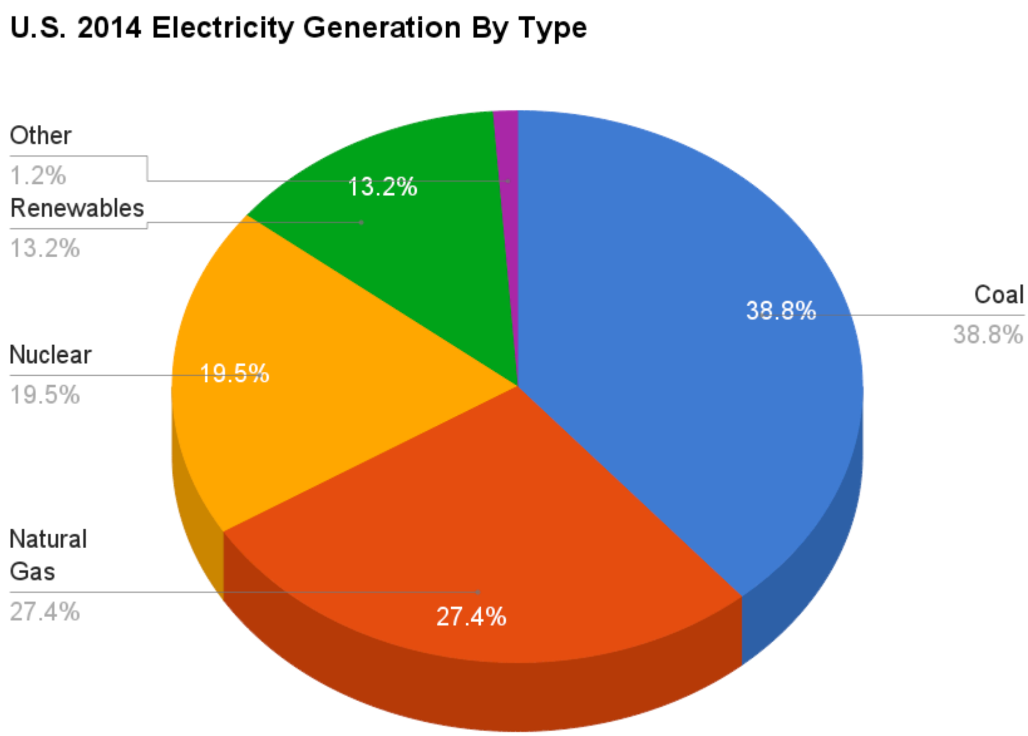

Figure: U.S. electricity generation by source in 2014
Source:https://commons.wikimedia.org/wiki/File:U.S._2014_Electricity_Generation_By_Type.png#/media/File:U.S._2014_Electricity_Generation_By_Type.png accessed 11/24/15, chart constructed from data at: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01

Worldwide, the picture is not hugely different in that coal is the primary source for electricity. In addition, natural gas and renewables provide an important component, as shown in the figure below. Projections of electricity sources in the future show renewables becoming more important than natural gas, but with coal still the most important source. Notice that the figure below shows world net electricity generation almost doubling between 2007 and 2035. This growth is due to increased demand bolstered by an increasing world population.

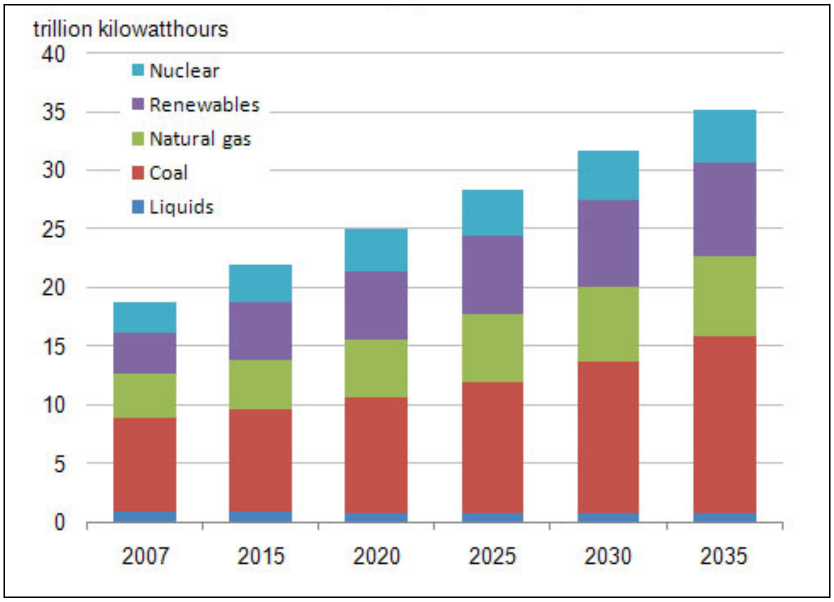

Figure: World net electricity generation by fuel, projected to 2035

Source: U.S. Energy Information Administration / International Energy Outlook 2010, http://www.eia.doe.gov/oiaf/ieo/highlights.html, accessed 3/2/2010

Glossary Source: NOAA, http://www.esrl.noaa.gov/gmd/education/terms.html; The Free Dictionary, http://encyclopedia2.thefreedictionary.com; Wikipedia, http://en.wikipedia.org/wiki/Permeability, http://en.wikipedia.org/wiki/porosity, http://en.wikipedia.org/wiki/Combustion, accessed 3/3/2010

Carbon dioxide - CO_2	A colorless, odorless gas consisting of molecules made up of two oxygen atoms and one carbon atom, produced by numerous processes, including respiration and burning of carbon-based fuels. It is the principal greenhouse gas in the Earth's atmosphere after water vapor
Climate change	A significant and lasting change to the state of the climate in a given area; typically this change occurs gradually due to natural variations, but change may also be forced more rapidly due to human activities which alter the composition of the atmosphere, the land surface, or ecosystems; although often used interchangeably with the term “global warming,” climate change can refer to other changes (e.g. changes in precipitation) in addition to rising temperatures,
Combustion	Sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat and conversion of chemical species. In a complete combustion reaction, a compound reacts with an oxidizing element, such as oxygen, and the products are compounds of each element in the fuel with the oxidizing element. For

example:

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O + \text{energy}$$

Electromagnetic Spectrum	The range of different types of radiation as characterized by wavelength and level of energy; in order of increasing wavelength (corresponding to decreasing energy content): X-rays, ultraviolet, visible light, infrared, microwaves, radio waves
Emissions	Substances discharged into the air (usually by a smokestack or automobile engine).
Green House Gases (GHGs)	Gases in the atmosphere that contribute to the Greenhouse Effect due to properties which absorb and emit infrared radiation. In Earth's atmosphere, these gases include water vapor, carbon dioxide, water vapor, methane, nitrous oxide and chlorofluorocarbons (CFCs).
Greenhouse effect	A process which warms the earth's atmosphere due to the absorption of radiation energy by several trace gases; these greenhouse gases allow solar radiation to reach the earth's surface but then absorb the energy as it is reemitted as infrared radiation, acting to contain the heat within the atmosphere; this occurs naturally and is increased by humans
Hydrocarbon	Substance containing the elements carbon and hydrogen.
Infrared Radiation	Electromagnetic radiation that has a wavelength just greater than that of red light but less than that of microwaves, emitted particularly by heated objects.
Methane - CH_4	A colorless, odorless, flammable, non-toxic consisting of molecules made up of four hydrogen atoms and one carbon atom; it is the main constituent of natural gas; is released in environments in which organic matter decomposes without enough oxygen. It is one of the major greenhouse gases in Earth's atmosphere.
Permeability	Measure of the ability of a material (such as rocks) to transmit fluids
Porosity	Measure of the void spaces in a material, and is a fraction of the volume of voids over the total volume, between 0–1, or as a percentage between 0–100%.
Reservoir rock	A naturally occurring storage area that traps and holds petroleum, water or other substance in small spaces (pores) within the rock. The reservoir rock must be permeable and porous to contain the gas or water, and it has to be capped by impervious rock in order to form an effective seal and prevent the substance from escaping. Typical reservoir rocks are sandstones with high porosity and permeability, but can also include fractured limestones and dolomites.
Solar Radiation	Energy emitted by the sun composed mostly of visible and ultraviolet light.

Ultraviolet Light	Shortwave radiation within the ultraviolet range of the electromagnetic spectrum; lies beyond the visible spectrum of light and contains wavelengths of approximately 100-400 nanometers; is harmful to most organisms.
Visible Light	Radiation within the range of the electromagnetic spectrum that is visible to the human eye; wavelengths of visible light range from approximately 400-700 nanometers

ACKNOWLEDGEMENTS

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This activity is sponsored by:

Learning Experience 1: Chemistry of Burning

Many people do not understand the connection between the burning of fossil fuels and the increase of CO_2. Why is CO_2 increasing in the atmosphere? Who or what is responsible? This short activity demonstrates how CO_2 is created from the simple activities we do everyday that are based on the burning of fossil fuel, for example, driving a car, using electricity (derived from a coal-fired or natural gas-fired power plant).

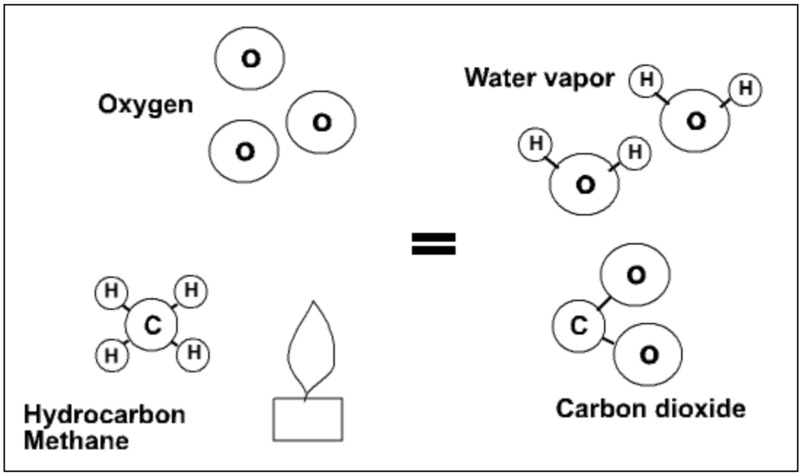

Figure 1. Models made of Styrofoam balls are used to illustrate the chemistry of combustion.

Objectives

This learning activity is designed to:

(1) introduce or review basic chemistry, specifically:

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ + energy

(2) show that producing CO_2 is an inevitable waste product of burning any fossil fuel

Time Frame: 15 minutes

Materials

- Styrofoam balls in three sizes (for example: 1, 1¼, 1½ inch)
- Paint to color balls in three contrasting colors
- Precut, 1-inch-long pieces of pipe cleaner
- Candle and match

Advance Preparation

Prepare a box of different-sized Styrofoam balls painted to represent oxygen (largest ball, at least four), carbon (medium-sized ball, at least one), hydrogen (smallest ball, at least four). Cut several pipe cleaners into 1-inch lengths. A candle is also needed.

Procedures for Guided Inquiry Activity

Ask "What did you do today that used energy?" and "Where did that energy come from?" You could have students make a lists and present at the front of the classroom. (Answers might include driving to school with a parent, taking a hot shower in the morning, using a hair dryer, getting cold milk out of the refrigerator.)

Ask "What is in a hydrocarbon?" (Answer: hydrogen and carbon). One carbon atom attached to four hydrogen atoms is methane, the simplest hydrocarbon molecule. Have participants make hydrocarbons (in this case methane: CH_4) by linking Styrofoam balls representing hydrogen (small) with carbon (medium sized) with the pieces of pipe cleaner.

Ask "How do we get energy from hydrocarbons?" (Answer: burn it, which means that oxygen must be added to the fuel in the presence of threshold heat.) If time allows, light a candle using a match, and let these ideas sink in—hydrocarbons are from the candle (or you could use an oil lamp), and oxygen is from the air. Point to or hold up the methane molecule, add two large Styrofoam balls (oxygen) to the medium-sized ball (carbon), and pull the hydrogen atoms off (Say "pop" or "bang" as you do it to symbolize the release of energy). Then add two hydrogen balls to each of two oxygen balls. These actions represent combustion.

Ask "What are the products of fossil-fuel combustion?" Coach the audience to figure out the answer from the model (CO_2 = carbon-di-oxide and H_2O is water). Throw the molecules in the air to emphasize what happens to them under normal circumstances. People are usually surprised that water is released by combustion. Ask them to think about what they have seen coming out of tailpipes of cars or from smokestacks or chimneys on cool mornings. (White "smoke" is water vapor condensing.) Although people cannot see CO_2, at least half as much CO_2 as water is produced in most kinds of combustion.

Learning Experience 2: Seeing the Carbon in CO_2

How much CO_2 is produced during combustion of fossil fuel?

Objectives

This demonstration creates a visual to:

(1) allow students to calculate the CO_2 emissions from several types of fossil fuels, specifically coal and petroleum

(2) allow students to see the amount of carbon going into the atmosphere when we do things like drive our car

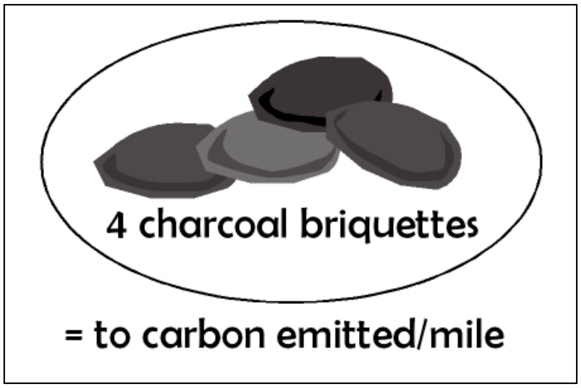

Figure. Briquettes help people imagine carbon in CO_2 emissions.

Time Frame: 15 minutes

Materials

- 5-lb bag of charcoal briquettes
- Large white garbage bag or other table cover (on which to spread briquettes)
- Pre-moistened towelettes for clean up

Advance Preparation

1. Pour charcoal out on a white plastic bag as a visual aid.

Procedures for Guided Inquiry Activity

1. Explain: One gallon of gasoline has about 5.2 lb (2.3 kg) of carbon. Charcoal briquettes are almost all carbon.
2. A 5-lb bag of charcoal holds about 100 briquettes. At 26 miles/gallon, calculate how many lbs of carbon that is per mile. Participants can count out briquettes to equal the amount of carbon that will be released to the atmosphere during a normal drive.

Thinking Questions

1. "A standard U.S. car throws a charcoal briquette (or more) of carbon from its tailpipe about every ¼ mile. If people could see the carbon that was being released when everyone threw the equivalent of a briquette out of his or her car every ¼ mile, would it make a difference in how people act?"

Learning Experience 3: What is the Greenhouse Effect?

This visual analogy provides a way to think about atmospheric physics in terms of familiar objects

Objectives

This learning activity is designed to demonstrate:

(1) an easy visualization of the greenhouse effect

(2) how increasing CO_2 in the atmosphere increases global temperature

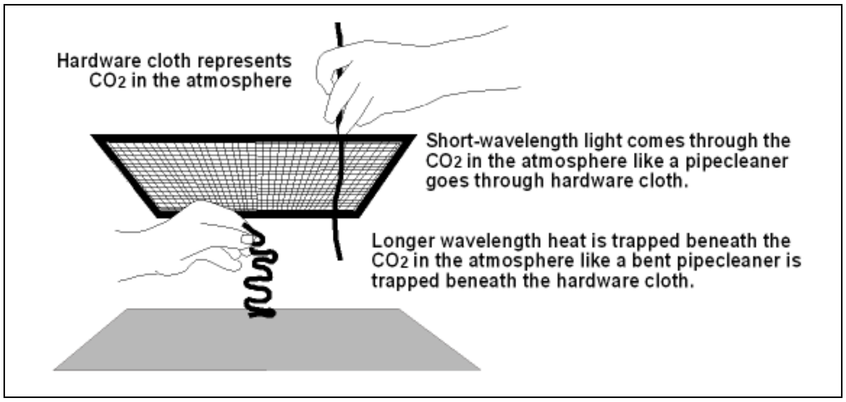

Figure. Model of interaction of atmosphere with light and heat.

Time Frame: 15 minutes

Materials

- Two 10" × 10" sheets of 4 wires/inch (¼-inch mesh), galvanized hardware cloth from a builders' supply store
- Tape to seal sharp cut ends of hardware cloth
- Several ordinary pipe cleaners from a craft shop

Advance Preparation

1. Cut hardware cloth (wire mesh having ¼-inch openings) into two pieces about 10" × 10" square. Fold heavy tape over all sharp edges to make them safe to handle.

Procedures for Guided Inquiry Activity

1. The hardware cloth helps us imagine how CO_2 in the atmosphere interacts with light and heat energy. Whoosh the hardware cloth through the air to show its small resistance to wind—it is because only a little bit of wire is in the hardware cloth. It is like CO_2 in the atmosphere in that only a little bit of CO_2 is mixed in with other gasses to make up the Earth's atmosphere.

2. A pipe cleaner represents the light energy coming from the sun, which has a short wavelength. The fuzz on the pipe cleaner represents the wavelength of light.
3. Have a volunteer hold the hardware cloth (CO_2 in the atmosphere) horizontally above a table, so that it looks like the atmosphere as seen from space. Push the pipe cleaner through the hardware cloth to show how light from the sun can easily go through the atmosphere.
4. Ask: But what happens to the light after it hits the Earth? Does it all reflect back as light into space? Think about the effect of sunshine hitting the ground on a summer day. (Some light is absorbed by objects and the ground and then radiated as heat).
5. Heat energy has a longer wavelength than light. The pipe cleaner bent in five or six zigzags can represent this wavelength. Have participants bend the pipe cleaner into a long-wavelength spring.
6. Have participants try transmitting this long-wavelength heat energy through the CO_2 in the atmosphere (hardware cloth). It will not go through because the "heat" is trapped and bounces around between the atmosphere and Earth.
7. Layer another sheet of hardware cloth over the first to represent more CO_2 in the atmosphere. Ask: Will this make it harder for heat to escape? The CO_2-rich atmosphere is trapping heat just like the glass roof of a greenhouse does (hence the name greenhouse effect).

Thinking Questions

(1) Do you think that society should be concerned about the release of too much CO_2 in the atmosphere? Why? What could happen if the earth warms up significantly in the next several decades?

Learning Experience 4: CO_2 is a Gas

Is CO_2 dangerous? Does it explode? Can it be transported safely?

This set of experiments is used in introductory physics and chemistry classes to examine properties of gasses. Our motive here is to increase student understanding of the basic properties of CO_2 so that they can be informed about safe handling of the gas.

Objectives

This demonstration creates visuals to:

(1) demonstrate some basic properties of CO_2

Time Frame: 15 minutes

Materials

- 10-gallon aquarium or similar container (plastic containers work well and can be easily transported)
- Plastic tray to fit inside aquarium (dry ice placed directly on glass may crack it; a container provides insulation)
- Bubbles and bubble-blowing wand from a toy store
- Candle
- Matches or lighter
- Several clear-plastic 12-oz cups
- Two hot pads (gloves also work) for safe handling of dry ice
- Several 1-pint water bottles filled with drinking water
- balloons
- Ice pick
- Plastic bag to cover work surface
- 5- to 12-lb block of dry ice
- Small Styrofoam ice chest for transporting dry ice

Advance Preparation

(1) Freeze caution: warn students not to touch dry ice with bare skin.
(2) Using hot pads or gloves, place the dry-ice block into a shallow plastic tub.
(3) The plastic will provide insulation so that the cold from the dry ice will not crack the glass. Use the ice pick to break off a number of chunks of dry ice, ice-cube size or smaller, for the experiments. Place the dry ice in the tub into the bottom of a 10-gallon fish tank or similar container.

Procedures for Guided Inquiry Activity

(1) In a turbulent or breezy setting it is helpful to cover the tank with a piece of newspaper (or the top to a plastic container if you are using that rather than an aquarium) to allow

the CO_2 to build up and to break the dry-ice block into more pieces to increase the rate of sublimation. This experiment is not really suitable for outside demos.

(2) Dry ice is frozen CO_2. Ask: Does anyone know where the CO_2 goes as the dry ice sits in the room and warms up? Do you see any liquid CO_2 drips? (No, liquid CO_2 does not exist at atmospheric pressure. Frozen CO_2 "thaws" or sublimes directly to gas.) Can anyone see the CO_2?

(3) Even though CO_2 gas is invisible (transparent to light), we can test for it. CO_2 gas is heavier than air (air is mostly nitrogen and oxygen). So if we blow bubbles full of regular air, they will float on CO_2 . Have participants try it. Participants should blow soap bubbles gently into the tank and watch them "float" on CO_2. Too vigorous swooshing of the bubble wand or blowing of bubbles will displace the CO_2 and no effect will be seen.

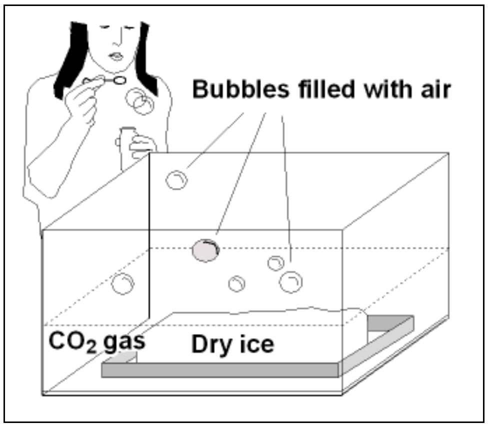

Figure. Using the property of density to test for CO_2 gas that collects in the tank as dry ice sublimes.

(4) Another way to see the gas is to collect it. Fill a small water bottle nearly to the top. Drop an ice-cube-size piece of dry ice (broken in several pieces) into the water. Put a balloon over the top of the bottle, and watch the CO_2 gas blow up the balloon.

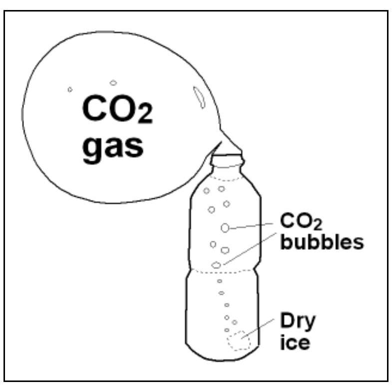

Figure. As dry ice sublimes, gas expands and fills the balloon.

(5) Ask: Is CO_2 dangerous? Is it explosive? CO_2 collects in low places and displaces lighter oxygen. If a hamster were put in a tankful of CO_2, it would die. If we light a candle and put it in the tank, we will see that there is not enough oxygen for the candle to burn. Have participants try putting a lit candle into the tank.

(6) CO_2 is not explosive; it is used to put out fires. Slowly fill a plastic cup with CO_2 gas from the bottom of the aquarium and pour it onto a lighted candle (short, fat candles are easiest to hit).

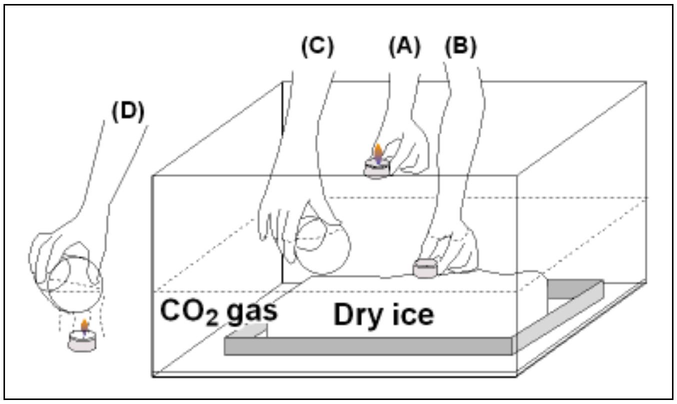

Figure. Testing for CO_2 by extinguishing flame.

(7) In low and moderate concentrations, CO_2 is not dangerous to people. Have students pour a transparent cup half full of drinking water. Add a small cube of frozen CO_2. The water warms the frozen CO_2 causing it to form gas, which fizzes (CO_2 makes the fizz in carbonated beverages). As some of it dissolves in the water, it forms a weak acid. If you drink the water, it tastes slightly tangy (like lemon), which is the taste of acid. (This part of the experiment has proven to be very popular. Don't let students touch the dry ice, though.)

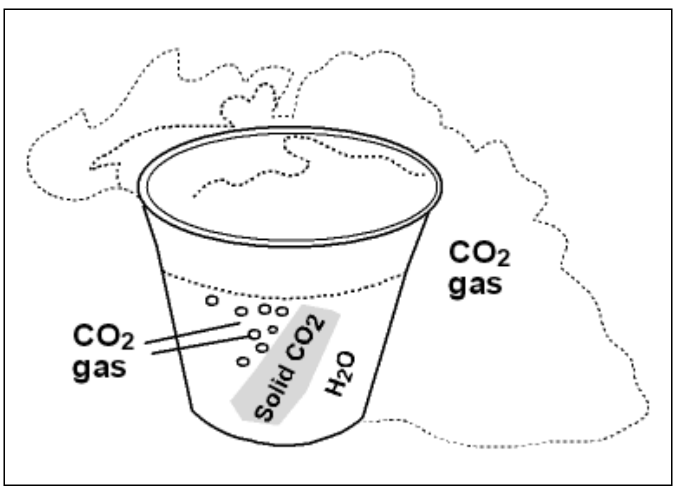

Figure. Making carbonated water with dry ice.

Thinking Questions

(1) How are you exposed to CO_2 in your day-to-day life? What misconceptions do you think people may have about CO_2?

Learning Experience 5: Reservoir in a Jar

Scientists and engineers have determined that one of the options to releasing CO_2 into the atmosphere is to capture it and store or "sequester" it underground. What exactly does that mean? Some students have misconceptions about reservoir rocks and imagine a big cave, which seems like it might collapse or blow out if you fill it with CO_2. This model lets them see how CO_2 could be stored underground in pores in the rock and how it is trapped by reservoir seals and phase trapping.

Objectives

This learning activity is designed to demonstrate:

(1) Storage of fluids underground in reservoir rocks

(2) Concepts of porosity and permeability

(3) Trapping mechanisms for CO_2 underground in reservoirs

Time Frame: 15 minutes

Materials

- Clear glass marbles from hobby or garden supply (enough to fill the jar); better if they are not of uniform size
- 1-quart jar (clear, with water-tight lid)
- Colored lamp oil from hobby or hardware store
- Tap water to fill jar

Advance Preparation

1. Check the clear glass jar to make sure that the lid can be fastened water-tight. Just like real CO_2 storage, we want to make sure that our demo doesn't leak. Fill the jar with clear glass marbles, but don't overfill. Several sizes of marbles make the model more interesting. Add 2 to 3 oz of colored lamp oil. Fill the jar with tap water, and put the lid on tightly.

Procedures for Guided Inquiry Activity

1. The jar shows you what you would see if you had a microscopic view of a CO_2 storage site underground. The marbles are sand grains, and the water is salt water that fills the spaces.

   Have students tip the jar from vertical to near horizontal and watch the "CO_2" move through the holes in between the marbles. CO_2 floats on top of water, so it tries to move upward. It is held underground by seals on the injection zone, just like this "CO_2" is held in by the sides and walls of the jar.

The small pores are the "microcaves" that would store the CO_2 underground. CO_2 is also prevented from escape because it is trapped as small bubbles snap off from the main body. This is a persistent characteristic of two-phase behavior, and it may be important in ensuring that CO_2 stays underground. Try jostling the bottle. It is pretty hard to get those phase-trapped bubbles to move!

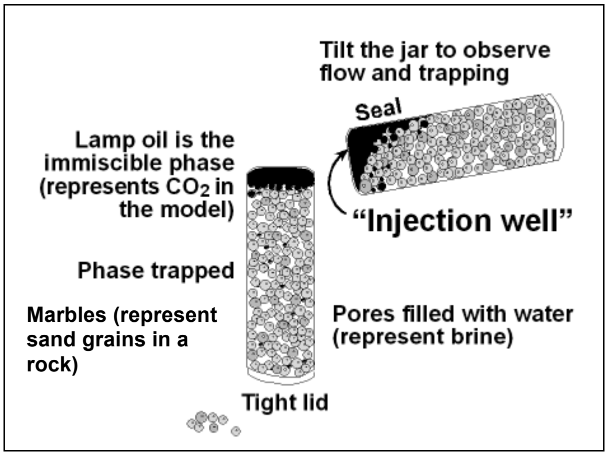

Figure. Using marbles in a jar to help visualize two-phase flow underground.

RESOURCES

Books:

1. Andrew Dessler and Edward A. Parson, 2010, *The Science and Politics of Global Climate Change: A Guide to the Debate,* Cambridge University Press, 211p.

DVDs:

1. Earth The Operator's Manual (http://www.pbs.org/programs/earth-the-operators-manual/)

Web Sites:

1. http://www.esrl.noaa.gov/gmd/education/lesson_plans/ Lesson plans on climate change from the National Oceanographic and Atmospheric Administration's website.
2. http://www.storeco2now.com A variety of items related to training, outreach, research and education related to carbon sequestration work at The University of Texas at Austin
3. http://www.gulfcoastcarbon.org Website of the Gulf Coast Carbon Center and their sequestration research efforts at The University of Texas at Austin
4. http://www.beg.utexas.edu/education/co2_outreach/co2_outreach03.htm online resource for the initial format of this activity as public outreach; includes videos of some of the demonstrations
5. http://keystone.org/node/355 Climate Status Investigations by the Keystone Group includes numerous middle school activities on the topic of climate change and provides new ways of thinking about the problem and potential solutions.