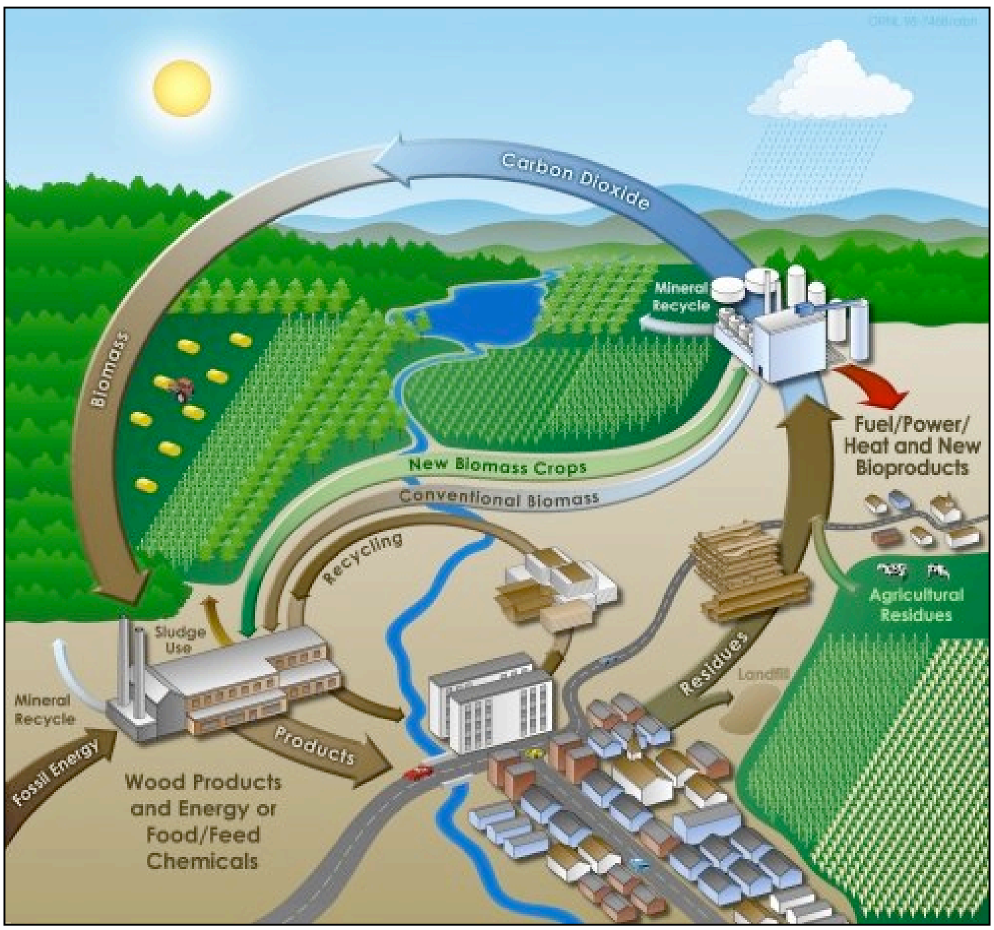
The Biomass Balancing Act (Teacher Notes)

(An Investigation of Biomass as a Sustainable Energy Resource)

The following notes are an excellent reference on the basics of bioenergy to be used in Part 3 of this lesson. The following is a public domain document courtesy of the Oak Ridge National Laboratory (ORNL) that can be accessed at: http://bioenergy.ornl.gov/papers/misc/bioenergy_cycle.html.

Bioenergy is produced in a cycle. Sustainable use of natural energy flows mimics the Earth's ecological cycles and minimizes the emission of pollutants into the air, rivers and oceans. Most of the carbon to create it is taken from the atmosphere and later returned to the atmosphere. The nutrients to create it are taken from the soil and later returned to the soil. The residues from one part of the cycle form the inputs to the next stage of the cycle.

Carbon dioxide (CO2) is withdrawn from the atmosphere by the process of plant growth (photosynthesis) and converted into vegetation biomass (trees, grasses, and other crops). Harvested biomass, together with forestry and crop residues, can be converted into building materials, paper, fuels, food, animal feed and other products such as plant-derived chemicals (waxes, cleaners, etc.). Some crops may be grown for ecological purposes such as filtering agricultural run-off, soil stabilization, and providing habitat for animals as well as bioenergy. The solid biomass processing facility (represented by the factory building at the bottom left) may also generate process heat and



electric power. As more efficient bioenergy technologies are developed, fossil fuel inputs will be reduced. Organic by-products and minerals from the processing facility may be returned to the land where the biomass grew, thereby recycling some of the nutrients such as potassium and phosphorus that were used for plant growth.

Selected residues from the town may be combined with forestry and crop residues, animal wastes, and biomass crops to provide the feedstocks for a different type of biomass processing (represented by the factory at the top right). This new biomass processing facility (or biorefinery) could make a range of products -- fuels, chemicals, new bio-based materials, and electric power. Animal feed could be an important co-product of some processes. Such biomass processing facilities would use efficient methods to minimize waste streams and would recycle nutrients and organic materials to the land, thereby helping to close the cycle.

Biomass products (food, materials, and energy) used by the human population are represented by the town at the bottom of the diagram. The residues from the town (scrap paper and lumber, municipal refuse, sewage, etc.) are subject to materials and energy recovery, and some may be directly recycled into new products.

Throughout the cycle, carbon dioxide from biomass is released back into the atmosphere -- from the processing plants and from the urban and rural communities -- with little or no net addition of carbon to the atmosphere. If the growing of bioenergy crops is optimized to add humus to the soil, there may even be some net sequestration or long-term fixation of carbon dioxide into soil organic matter. The energy to drive the cycle and provide for the human population comes from the sun, and will continue for many generations at a stable cost, and without depletion of resources.

For additional information, contact the Bioenergy Feedstock Development Program, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6422, (865) 574-576-5132

Additional Resources

Included below is a tremendous compilation from the Renewable Energy Policy Project from the Center for Renewable Energy and Sustainable Technology (CREST) that may be accessed electronically with embedded visuals at: http://www.repp.org/bioenergy/link1.htm.

Bioenergy

Forward

The purpose of this paper is to provide the reader with comprehensive knowledge of the biomass energy sector. Biomass is plant matter and animal waste that can be harvested to create bioenergy in the form of electricity, heat, steam and fuels.

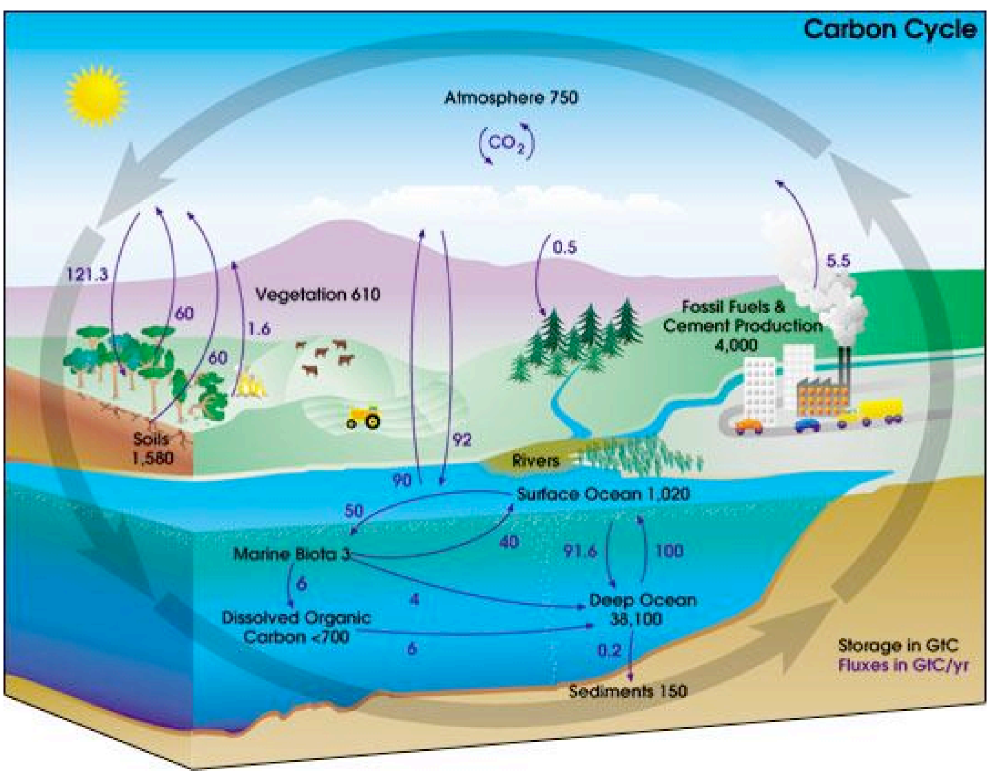
Biomass has great potential to contribute considerably more to the renewable energy sector. Already, in the U.S., residues from mill operations are the largest source of biomass for power plants and combined-heat-and-power projects. Photo Credit: NREL biomass research website Agricultural residues such as orchard prunings and nut hulls as well as forest residues are also important contributors to power plants in combined heat and power (CHP) operations, particularly in California. Landfill gas projects are growing steadily, while animal waste digestion projects and energy crop plantations are still at an early stage of commercialization. [1]

In Europe, urban wood waste is an important source of bioenergy. In developing nations, a major source of biomass is timber cut by the rural poor specifically for heating and cooking. [1]

Biomass Basics and Environmental Impact
Introduction
Biomass is any organic matter, particularly cellulosic or lingo-cellulosic matter, which is available on a renewable or recurring basis, including trees, plants and associated residues; plant fiber; animal wastes; industrial waste; and the paper component of municipal solid waste [2].
Plants store solar energy through photosynthesis in cellulose and lignin cells. Cellulose is defined as a polymer, or chain, of 6-carbon sugars; lignin is the substance, or “glue,” that holds the cellulose chain together [2]. When burned, these sugars break down and release energy exothermically, giving off CO2, heat and steam. The byproducts of this reaction can be captured and manipulated to create electricity, commonly called biopower, or fuel known as biofuel. (Both short for "biomass power" and "biomass fuel" respectively) [3].

Biomass is considered to be a replenishable resource—it can be replaced fairly quickly without permanently depleting the Earth’s natural resources. By comparison, fossil fuels such as natural gas and coal require millions of years of natural processes to be produced. Therefore, mining coal and natural gas depletes the Earth’s resources for thousands of generations. Alternatively, biomass can easily be grown or collected, utilized and replaced.

Moreover, using biomass to create energy has positive environmental implications. Carbon dioxide is a naturally occurring gas. Plants collect and store carbon dioxide to aid in the photosynthesis process. As plants or other matter decompose, or natural fires occur, CO2 is released. Before the anthropomorphic discovery of fossil fuels, the carbon dioxide cycle was stable; the same amount that was released was sequestered, but it has since been disrupted. In the past 150 years, the period since the Industrial Revolution, carbon dioxide levels in the atmosphere have risen from around 150 ppm to 330 ppm, and are expected to double before 2050! (please see diagram below)



Courtesy of NASA at http://rst.gsfc.nasa.gov/Sect16/carbon_cycle_diagram.jpg

An overwhelming majority of scientists now link carbon dioxide with rising temperatures in the atmosphere and other issues associated with climate change. Scientists are predicting a rise in average temperature 2-10 degrees Celsius. This change may seem insignificant, but note that the former ice age resulted from an average of 5 degrees Celsius drop in temperature [4]. This small shift in average temperature has huge implications for melting ice sheets, which would raise global water levels up to 30 feet, flooding the coastal cities in which most of the world currently resides. Additionally, more extreme weather patterns are predicted to occur, as well as habitat loss, spread of disease and a whole host of other problems. The amount of CO_2 pumped into the atmosphere today will remain for at least a hundred years, since the half life will outlive all of us.

In order to curb CO_2 emissions, we must take active strides to reduce our emissions. At present, the United States is responsible for 25% of the world's emissions, and is currently dedicated to a policy which actually encourages the release of more carbon dioxide into the atmosphere, claiming it to be an indication of economic growth. Burning biomass will not solve the currently unbalanced carbon dioxide problem. However, the contribution that biomass could make to the energy sector is still considerable, since it creates less carbon dioxide than its fossil-fuel counterpart. Conceptually, the carbon dioxide produced by biomass when it is burned will be sequestered evenly by plants growing to replace the fuel. In other words, it is a closed cycle which results in net zero impact (see diagram below). Thus, energy derived from biomass does not have the negative environmental impact associated with non-renewable energy sources. [5]

Biomass is an attractive energy source for a number of reasons. First, it is a renewable energy source as long as we manage vegetation appropriately. Biomass is also more evenly distributed over the earth's surface than finite energy sources, and may be exploited using less capital-intensive technologies. It provides the opportunity for local, regional, and national energy self-sufficiency across the globe. It provides an alternative to fossil fuels, and helps to reduce climate change. It helps local farmers who may be struggling and provides rural job opportunities. [6]

Bioenergy ranks second (to hydropower) in renewable U.S. primary energy production and accounts for three percent of the primary energy production in the United States [7].

Biomass Energy Conversion

Bioenergy conversion requires a comparison with other energy sources that are displaced by the bioenergy. Thus, biomass for power must be compared to coal, natural gas, nuclear, and other power sources including other renewables. While comprehensive data is not available, one study by REPP shows that emissions from biomass plants burning waste wood would release far less sulfur dioxide (SO_2), nitrogen oxide (NO_x) and carbon dioxide (CO_2) than coal plants built after 1975. The comparison with combined cycle natural gas power plants is more ambiguous, since biomass releases far more sulfur dioxide, similar levels or greater levels of nitrogen oxide, but far less carbon dioxide than combined cycle natural gas plants.

Life-cycle impacts

Several studies by the National Renewable Energy Laboratory examined the “life-cycle” impact of bioenergy for power. That is, the studies examined the air, land and water impacts of every step of the bioenergy process, from cultivating, collecting, and transporting biomass to converting it to energy. One study found that a bioenergy operation featuring biomass gasification with combined-cycle power plant technology would release far less SO_2, NO_x, CO_2, particulate matter, methane and carbon monoxide than coal power plants meeting new federal air pollution standards.

Sources Cited:

[1] Center For Renewable Energy and Sustainable Technology (CREST). Biomass FAQs. Discussion Section. www.repp.org.

[2] "What is Biomass?" American Bioenergy Association. http://www.biomass.org/index_files/page0001.htm May 12, 2005

[3] "Biomass FAQs." Office of Energy Efficiency and Renewable Energy. Department of Energy. http://www.eere.energy.gov/biomass/biomass_basics_faqs.html#biomass. July 2005.

[4] "History of Climate Change." Athena Curriculum Earth, an affiliate of NASA. Available Online at http://vathena.arc.nasa.gov/curric/land/global/climchng.html, as of June 24, 2005.

[5] "Bioenergy." http://www.montanagreenpower.com/renewables/bioenergy/ May12, 2005.

[6] Kirby, Alex."UK Boost for Biomass Crops." BBC News Science and Nature. http://news.bbc.co.uk/1/hi/sci/tech/3746554.stm. Oct 19, 2004.

[7] See Footnote 3

Carbon Dioxide Presence Demonstration

(Adapted from Project Learn's "Where in the World is Carbon Dioxide?" Activity)

This demonstration requires some preparation, but is an excellent way to get students thinking about how they could quantify the carbon dioxide releases associated with bioenergy production, especially if your students have not previously worked with indicator solutions.

Materials:

- Manila folder
- Roll of duct tape
- Pair of heat resistant oven mitts
- Balloons (8 or 10-inch diameter)
- test tubes
- test tube rack
- 1 test tube stopper with a length of flexible tubing attached
- Bromthymol Blue (BTB) solution
- Vinegar
- Baking soda
- Dilute solution of ammonia in dropper bottle
- Cotton balls
- 1" X 1" Aluminum foil square (shaped into a small cone)
- 10-12 twist ties

PART 1: DETECTING CARBON DIOXIDE GAS

BTB is available in either concentrated liquid or powdered form. Do the following to prepare the BTB solution.

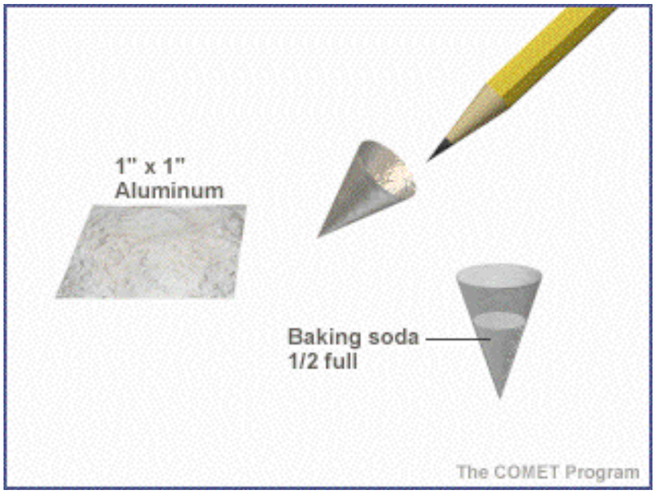
- If you're using the liquid form
    - Fill a gallon bottle nine-tenths full with tap water and add BTB until the solution is a deep, blue color (this is the working solution).
- If you're using powdered BTB
    - Measure 0.5 grams of dry BTB into 500 ml of tap water. This will provide a 0.1% stock solution.
    - To prepare the working solution, mix 1 part stock solution with 20 parts tap water.

[One liter of working solution could serve a class of 30 students, in two-person teams.]

In Part 1, explain that the demo is an experiment designed to detect the presence of CO_2. When combined, baking soda and vinegar produce pure CO_2. In this experiment, the BTB will dramatically change color (from bright blue to yellow) when introduced to the CO_2.

1. Fill tubes A and B approximately 1/3 full with the BTB solution.

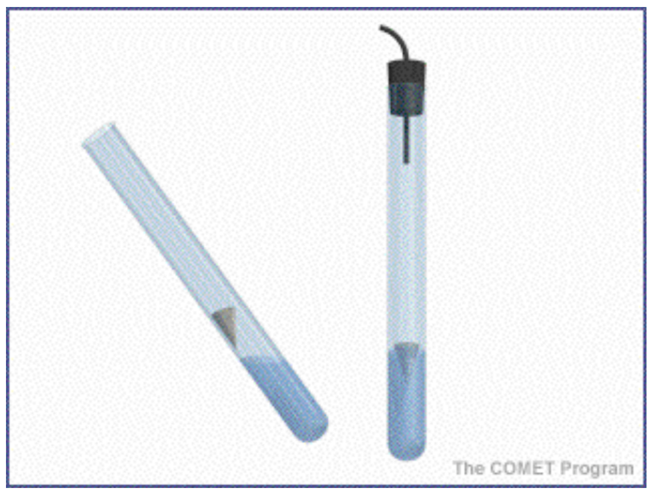
2. Note the color of the solution in test tubes A and B. Tube A will be the control, tube B will be the treatment. Place the tubes in the rack.



3. Fill the unlabeled tube approximately 1/4 full of vinegar.

4. Using the foil, make a small "boat" for the baking soda - fill 1/2 full of baking soda (see diagram to the left). The 'boat' should be small enough to easily fit into the test tube and float on the vinegar.

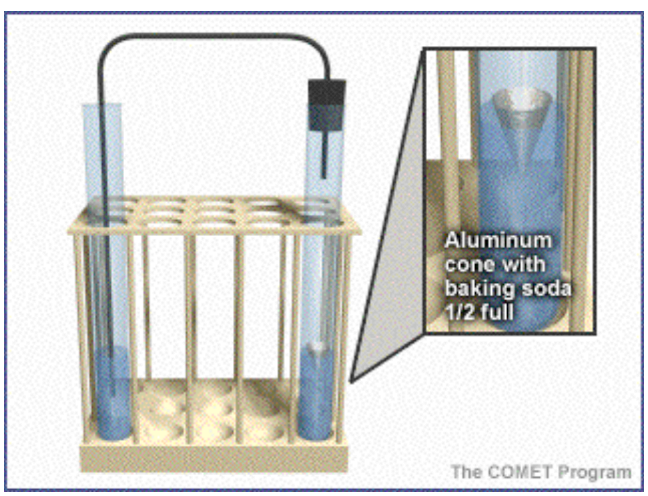
5. Carefully slide the foil boat inside the unlabeled vinegar test tube (see directly below).



6. Plug the tube with the stopper and tubing.

7. Place the free end of the tubing in tube B, making sure the end of the tubing reaches the bottom of the tube.

8. Place a cotton ball into the neck of Tube B.



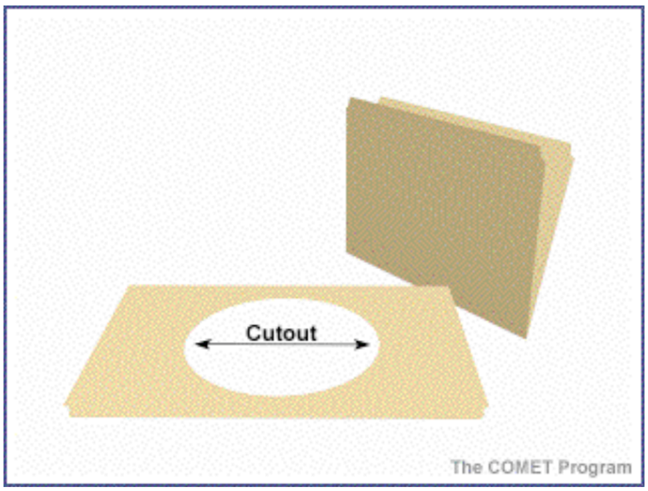
9. Mix the vinegar and soda together by GENTLY swirling the tube from side-to-side. Gas bubbles will begin to bubble rapidly out of the tubing into the BTB solution in tube B.

10. Note color after 1 minute.

PART 2: COLLECTING SAMPLES OF CARBON DIOXIDE FROM VARIOUS SOURCES (AIR, ANIMALS, AND FOSSIL FUELS)

The demo will compare the CO_2 from **car exhaust** (which will represent fossil fuel), **a volunteer's breath** (representing animals), and **the outside air** by bubbling a known amount of each gas though a standard volume of BTB. Students will witness how the different sources change the color of the BTB solution like the pure CO_2 in Part 1.

To make a meaningful comparison, it is important that equal volumes of gases are used. We suggest using rubber balloons blown up to the same diameter from each source as collectors. To do this, make a simple balloon diameter template with a piece of cardboard or half of a manila folder. Draw a circle about 7.5 cm in diameter in the middle. Cut out the circle and discard, saving the frame for use as a template.



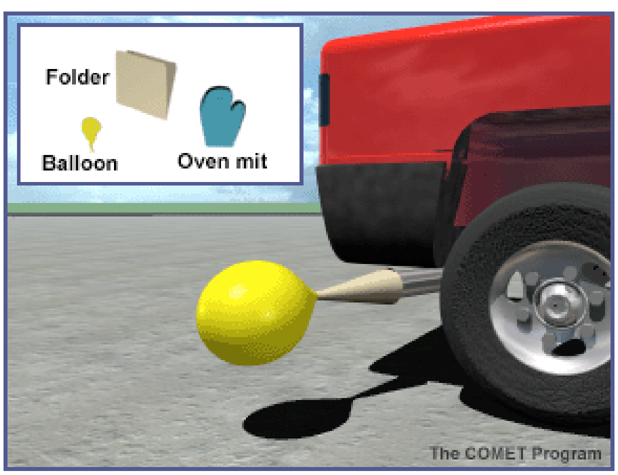
A. Automobile exhaust collection

Materials needed for collecting car exhaust:

- Manila folder
- Roll of duct tape
- Pair of heat resistant oven mitts
- Balloons (8 or 10-inch diameter)

1. Blow up and allow the balloons to deflate. This will stretch the rubber and make them easier to fill with the relatively low-pressure exhaust.

2. Prepare a cone to collect the car exhaust by rolling up a manila folder lengthwise. One end must be larger than the opening for the car's tail pipe and the other end must be small enough for the balloon to fit over it.



Use plenty of tape to hold the cone in shape and to make the sides of the cone fairly airtight. Note: the paper funnel will work for several fillings without burning. DO NOT use a plastic funnel. As the exhaust pipe heats up, the plastic may melt. You may use a metal funnel, but be VERY careful to avoid any skin contact with the hot metal.

3. Have an assistant turn on the car (make sure brake is on).

4. Put the balloon on the end of the cone.

5. Using the heat resistant mitts, approach the exhaust pipe from the side. Place the large end of the cone over the tail pipe. Use the gloved hand to help form a seal between the cone and the exhaust pipe. DO NOT BREATHE THE EXHAUST. The balloon should fill quickly; if not, have your assistant step lightly on the accelerator.

6. When the balloon is filled, have an assistant use a twist tie or two to tightly seal the balloon. Do this by twisting the neck several times and doubling it over once, then place the twist tie around the constricted area.

7. It is useful to prepare a few extra filled balloons.

B. Animal carbon dioxide collection

Recruit a student volunteer to fill a second balloon to template size and secure with 2 twist ties. Emphasize to the volunteer that they should hold air in their lungs for a few moments to allow plenty of exchange between O_2 being absorbed and O_2 being released in their lungs. Breaths that are too rapid will contain less CO_2 than normal exhalations.

C. Outside air collection

Recruit a pair of student to collect outside air using an air pump (or bicycle or sports ball pump) to blow up a balloon using the balloon template. Again secure with 2 twist ties. The sample collection must be done out-of-doors as inside air can be CO_2 enriched from breath.

D. Bubbling CO_2 into solution

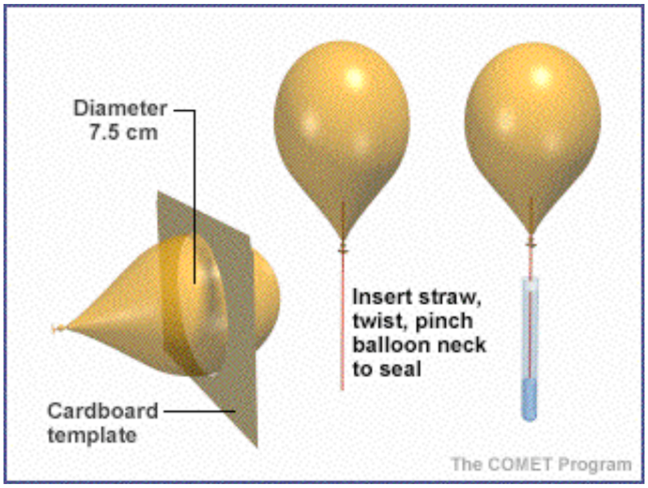
At this point, you will have three balloons, one of car exhaust, one of student breath, and one of outside air. Using the set-up shown below, bubble the gases through a BTB solution in test tubes, and allow students to observe the color changes. They should clearly observe the rapid and dramatic change with the car exhaust, the less significant change with their own breath, and the minor change with room air.

1. Place three pre-labeled [E-Exhaust, H-Human, O-Outside] empty test tubes in the test tube rack.

2. Fill each of the empty test tubes approximately 1/3 full of BTB. You may want to use the funnel to make this task easier.

3. Begin with the outside air sample (Balloon O). Insert the straw inside the neck of Balloon O and secure it with a twist tie. Do not remove the first twist tie (holding the balloon closed) at this time.

4. Insert the other end of the straw into the BTB solution in test tube O. Insert a cotton ball into the top of the test tube to help hold the straw in place.



5. Gently release air from the balloon by slowly untwisting the neck. Allow the air to bubble out at a steady rate until the balloon is empty. BE VERY CAREFUL TO ALLOW A SLOW AND STEADY GAS RELEASE.

6. Observe the color change (if any). Repeat steps 3 to 5 for each of the remaining balloons.

7. Allow students to observe the results of the test tubes. Arrange the test tubes in order by color (yellow to blue). Hint: It may be useful to hold a blank sheet of white paper behind the test tubes to better observe color differences.

8. Using the small dropper bottle, carefully add drops of diluted ammonia to each test tube. Explain to students (or ask students to explain what adding ammonia does to the system) that the number of drops of ammonia needed to turn the solution blue again is directly related to the amount of CO_2 it required to change the BTB color in the first place. Employ student drop counters and bubblers as needed to make the demonstration as interactive as is feasible.