CHEMMATTERS

February 2011 Teacher's Guide

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About the Guide

Teacher's Guide editors William Bleam, Donald McKinney, Ronald Tempest, and Erica K. Jacobsen created the Teacher's Guide article material.

Susan Cooper prepared the national science education content, anticipation guides, and reading guides.

David Olney created the puzzle. E-mail: djolney@verizon.net

Patrice Pages, *ChemMatters* editor, coordinated production and prepared the Microsoft Word and PDF versions of the Teacher's Guide. E-mail: chemmatters@acs.org

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Drugs Down the Drain: The Drugs You Swallow, the Water You Drink

1. How does the concentration of pharmaceuticals detected in U.S. drinking water compare to the therapeutic dose of any of the pharmaceuticals?
2. What are some examples of how pharmaceuticals dissolved in freshwater have affected fish?
3. What happens to the active ingredients in a drug when you take it?
4. Describe the path wastewater takes when it leaves your home, to when drinking water enters your home again.
5. What did stream testing in 1999 and 2000 in the U.S. reveal?
6. What are some drawbacks to using chlorine to disinfect wastewater?
7. What are some of the methods scientists are working on to remove pharmaceuticals from drinking water?
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Cleaning Up the Air

1. What is meant by the Carbon Cycle?
2. Other than the burning of fossil fuels (coal, oil, natural gas), what are two other “natural” or biological sources of carbon dioxide in the movement of the gas within the biosphere?
3. What biological process removes carbon dioxide produced by respiration and decay?
4. How is the respiration chemical equation related to the photosynthesis chemical equation?
5. What are the names and chemical formulas for the main greenhouse gases?
6. Why are the gases listed in question #5 called greenhouse gases?
7. What human activities have increased the amount of carbon dioxide in the atmosphere?
8. Why does the burning of coal not produce water compared with the burning of other fossil fuels such as natural gas and gasoline?
9. To produce the greenhouse effect in the atmosphere, what types of solar radiation (visible, invisible) are involved?
10. What prevents much of the heat produced at the earth’s surface (land, water, and atmosphere) from escaping into outer space (beyond our upper atmosphere)?
11. How can the injection of liquefied carbon dioxide gas into old oil reservoirs produce more oil?
12. What chemical reactions can be used to store carbon dioxide in rock formations rich in magnesium and calcium?

Kilimanjaro: Peering Through Disappearing Ice

1. The article describes “fossils” for climate and weather. Name three of them.
2. Where in the world have most ice cores been collected, and why these locations?
3. Name the two “greenhouse” gases that are trapped in air bubbles in ice cores and that are of interest to paleoclimatologists.
4. Name the sub-atomic particles that a) are the same in all isotopes of a given element and b) are different in these isotopes.
5. There are two isotopes of oxygen described in the article. Water made of which of these isotopes vaporizes most easily?
6. Aerial photographs of Mt. Kilimanjaro show that much of its ice sheet has been lost. What percent has been lost since 1912?

Answers to Student Questions

Recycling to Survive

1. **What do "rag pickers" do?**
   "Rag pickers" collect plastic objects from wastewater and deliver them to shops for recycling.
2. **Why do so many people in India recycle plastics?**
   Many in India recycle plastics as perhaps the only way they can earn enough to survive (see article title).
3. **What are the three types of structures for plastics?**
   The three structural types of plastics are linear, branched and cross-linked.
4. **What is the difference between thermoplastics and thermoset plastics?**
   Thermoplastics, usually linear of slightly branched polymers, can be reheated and reshaped into different shapes; thermoset plastics, once produced and shaped—and thus crosslinked, cannot be reheated and reshaped. They decompose upon extreme heating, rather than softening.
5. **List two thermoplastics and two thermoset plastics.**
   Polyvinyl chloride and polyethylene terephthalate are thermoplastics, and polyurethane and epoxy are thermosets.
6. **Name at least 5 uses for plastics in our everyday lives.**
   Plastics are used in electronic equipment, CDs, DVDs, clothing, cars, and packing for food, beverages and pharmaceuticals, just to name a few.
7. **What is the term for the source materials for almost all plastics?**
   The source material for almost all plastics is petrochemicals, derived from petroleum and natural gas.
8. **Name the two factors that drive the recycling industry worldwide.**
   The two factors driving recycling are the decreasing availability of petroleum and natural gas globally, and the almost infinite lifetime of plastics when placed in landfills.
9. **Name and describe the three recycling methods.**
   a) Physical recycling involves chopping the plastic into small pieces, washing the pieces, and melting them down so they can be molded or spun into new products;
   b) Chemical recycling involves reversing the chemical process that produced the plastic in the first place, producing the original raw materials, treating them to remove impurities, usually mixing these recycled raw materials with virgin raw materials, and using them to produce new plastic of the same type; and
   c) Thermal recycling involves heating the plastic with hot water and detergent to clean it, to prepare it for molding into new pieces.
10. **What are the health hazards that Ramzan faces in his work?**
    Ramzan faces possible bodily injury with the sharp blades of the machinery and he faces possible long-term health problems arising from inhalation of the plastic dust mentioned in the article.

Sewage: The Hottest New Resource?

1. **What are the different sources or constituents of wastewater (sewage) that leave a home?**

The sources or constituents of sewage include human waste, food, grease, soaps, water from sinks, showers, bathtubs, toilets, washing machines and dishwashers.

2. **What are the four stages of wastewater treatment?**
   The four stages of treatment are:
   a. physical treatment,
   b. biological treatment,
   c. filtration and
   d. disinfection
3. **What three properties of waste material in sewage allow for separation in the physical treatment stage?**
   The three properties of waste material that allow for separation include size of particles, solubility of various constituents, and the density of the waste material.
4. **What are the three steps used by bacteria to convert nitrogen-containing compounds into free nitrogen gas (N_2) that escapes into the atmosphere?**
   Different types of bacteria first convert the compound ammonia (NH_3) into the nitrite ion, NO_2^- by reacting with oxygen. The nitrite ion is changed into the nitrate ion, NO_3^- again by reacting with oxygen. Finally, the nitrate ion is converted to nitrogen gas by reacting with an organic (carbon-containing) molecule.
5. **What uses are made of non-potable wastewater that has undergone final treatment?**
   The wastewater can be used for non-drinking purposes such as irrigation, parks and roof gardens, boat-washing and cleaning tasks in the treatment plant itself.
6. **How is non-potable wastewater used to generate electricity?**
   In Santa Rosa California, treated wastewater is pumped up into the mountains where it is injected into mile-deep cracks in the earth, re-supplying dried-up geysers. Here the water is heated to boiling by the underground rocks producing steam that can be used to turn generators for electricity production.
7. **What is reverse osmosis as used in the treatment of disinfected effluent?**
   Reverse osmosis is a process in which water containing viruses and ions of common salts is forced by pressure to pass through a very fine membrane against a concentration gradient.
8. **What is removed from disinfected effluent using reverse osmosis?**
   Reverse osmosis is used to remove various dissolved inorganic salts.
9. **What is meant by "recharging" through the use of sanitized (disinfected) effluent water?**
   Recharging involves using perfectly drinkable water from treated effluent to either percolate down through soil that acts as an additional filter or is added to large bodies of water.
10. **What is one of the drawbacks in using chlorine as a disinfectant for wastewater treatment?**
    Chlorine can react with organic matter (carbon-containing molecules) to form cancer-causing molecules called trihalomethanes.

Drugs Down the Drain: The Drugs You Swallow, the Water You Drink

1. **How does the concentration of pharmaceuticals detected in U.S. drinking water compare to the therapeutic dose of any of the pharmaceuticals?**
   The highest concentration of any pharmaceutical detected in U.S. drinking water was approximately 5 million times lower than the therapeutic dose.
2. **What are some examples of how pharmaceuticals dissolved in freshwater have affected fish?**

Studies have revealed traces of common pharmaceuticals in the brains, livers, and muscles of freshwater fish. In another study, fish exposed to synthetic female hormones from birth-control pills developed both male and female reproductive organs. Another study showed that minnows exposed to antidepressants lost their instinct to avoid predators.

3. **What happens to the active ingredients in a drug when you take it?**
   When you take a drug, your body uses only a portion of the active ingredients. The rest is excreted and is released into the sewer system when you flush the toilet.
4. **Describe the path wastewater takes when it leaves your home, to when drinking water enters your home again.**
   Wastewater travels through underground pipes to a sewage treatment plant, where it is treated to remove harmful bacteria and toxins. Liquid discharge from sewage treatment plants is released into rivers, lakes, and reservoirs, where the water eventually is taken up by water treatment plants. The water treatment plants treat water to remove bacteria and other contaminants and produce potable water that is piped to your home.
5. **What did stream testing in 1999 and 2000 in the U.S. reveal?**
   Water sampling revealed that 80% of the waterways tested contained detectable levels of pharmaceuticals, insecticides, and fire retardants.
6. **What are some drawbacks to using chlorine to disinfect wastewater?**
   While chlorine completely removes some drugs present in water, others escape chlorine treatment. Another drawback is that chlorine can react with pharmaceuticals and personal-care products to form more toxic compounds.
7. **What are some of the methods scientists are working on to remove pharmaceuticals from drinking water?**
   Some potential solutions are adjusting the pH of water being treated to improve the effectiveness of chlorine disinfection, the use of activated charcoal filters, ozone treatment, cultivating bacteria to gobble up drugs, and educating consumers on proper disposal.
8. **What are some pros and cons of using ozone as a water disinfectant?**
   Pros include: Ozone is a more potent disinfectant than chlorine, works over a wide range of temperature and pH levels, and leaves no chemical residue in treated water. Cons include: A lack of a residual effect leaves water susceptible to contamination after treatment and its high energy cost.
9. **Describe the guidelines for disposing of unused medications.**
   Never flush or pour drugs down the drain unless the accompanying patient instructions advise you to. If no take-back drug programs are available locally, remove drugs from their containers, crush, and mix with an unappetizing substance, then seal in a plastic bag, and throw in the garbage.

Cleaning Up the Air

1. **What is meant by the Carbon Cycle?**
   The carbon cycle is the movement of carbon within the Earth’s system.
2. **Other than the burning of fossil fuels (coal, oil, natural gas), what are the two other “natural” or biological sources of carbon dioxide in the movement of the gas within the biosphere?**
   The two natural or biological sources of carbon dioxide are respiration and photosynthesis.
3. **What biological process removes carbon dioxide produced by respiration and decay?**
   The biological process that removes carbon dioxide is photosynthesis in plants.
4. **How is the respiration chemical equation related to the photosynthesis chemical equation?**

The respiration chemical equation is the reverse of the photosynthesis equation with a net energy input for photosynthesis and a net energy output for respiration.

5. **What are the names and chemical formulas for the main greenhouse gases?**
   The main greenhouse gases are water vapor (H_2O*), carbon dioxide (*CO_2*), methane (*CH_4*), nitrous oxide (*N_2O*), and ozone (*O_3*).*
6. **Why are the gases listed in question #5 called greenhouse gases?**
   These gases in the atmosphere are called greenhouse gases because they act like the glass in a greenhouse in which light passes through, is absorbed by various surfaces to become heat (infrared) and is unable to pass back out of the greenhouse glass (or the atmospheric gases).
7. **What human activities have increased the amount of carbon dioxide in the atmosphere?**
   The primary sources for increasing the amount of carbon dioxide include burning of coal, natural gas and gasoline (in automobiles).
8. **Why does the burning of coal not produce water compared with the burning of other fossil fuels such as natural gas and gasoline?**
   Coal does not contain the element hydrogen that is found in the molecules of natural gas and gasoline (see the formulas in the article).
9. **To produce the greenhouse effect in the atmosphere, what types of solar radiation (visible, invisible) are involved.**
   The types of radiation in the atmosphere that are involved in producing the greenhouse effect include most wavelengths of infrared and three types of UV including –C, –B, and –A.
10. **What prevents much of the heat produced at the earth's surface (land, water, and atmosphere) from escaping into outer space (beyond our upper atmosphere)?**
    The heat, as infrared, is absorbed by greenhouse gases in the atmosphere where some of the infrared radiation is re-emitted back to earth rather than out into space.
11. **How can the injection of liquefied carbon dioxide gas into old oil wells produce more oil?**
    The pressure from the carbon dioxide can force more oil up into oil-drilling rigs at the earth's surface.
12. **What chemical reactions can be used to store carbon dioxide in rock formations rich in magnesium and calcium?**
    The carbon dioxide can chemically react with magnesium and calcium to form carbonates of the two elements, permanently locking in the carbon dioxide as part of new compounds.

Kilimanjaro: Peering Through Disappearing Ice

1. **The article describes "fossils" for climate and weather. Name three of them**.
   The article mentions tree rings, pollen, marine sediments, and ice samples. Other acceptable answers, not described in the article, would be corals and microbial life.
2. **Where in the world have most ice cores been collected, and why these locations?**
   Greenland and Antarctica, because they are relatively easy to access and there is a lot of ice. Lonnie Thompson's research, described in this article, is important because much of it has taken place in mountainous regions of the tropics in locations difficult to access.
3. **Name the two "greenhouse" gases that are trapped in air bubbles in ice cores and that are of interest to paleoclimatologists.** *Methane and carbon dioxide are the two greenhouse gases of interest to paleoclimatologists.*
4. **Name the sub-atomic particles that a) are the same in all isotopes of a given element and b) are different in these isotopes.**

   a. *Isotopes of a given element have the same number of protons (because all atoms of a given element have the same number of protons) and electrons (since all atoms are neutral, the number of electrons must match the number of protons) and*
   b. *isotopes of a given element differ in the number of neutrons.*

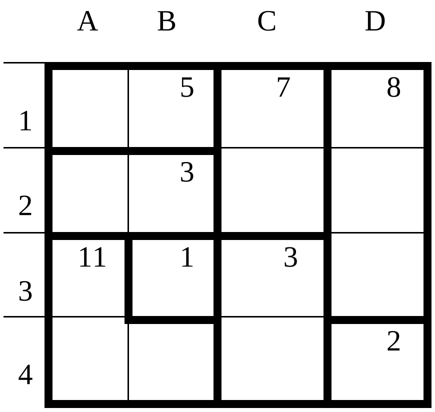
5. **There are two isotopes of oxygen described in the article. Water made of which of these isotopes vaporizes most easily?**
   Water made of the more abundant isotope O-16 vaporizes more easily, because it is lighter.
6. **Aerial photographs of Mt. Kilimanjaro show that much of its ice sheet has been lost. What percent has been lost since 1912?**
   About 85% of Mt. Kilimanjaro's ice sheet has been lost since 1912.

ChemMatters Puzzle: Chemical Ken-Ken

Like its big brother SUDOKU, KEN-KEN is a logic game from Japan. In the left-side grid shown, you're objective is to fill the digits 1-4 in so that each appears exactly once in each row and each column. Notice that most boxes are part of a cluster. In the upper-right corner of each cluster is a value that is the SUM of its numbers. For example, if that value is 3 for a two-box cluster, you know that a 1 and 2 go in there. But it's your job to determine which goes where! A few clusters may have just one box, and that is the digit that fills that box.

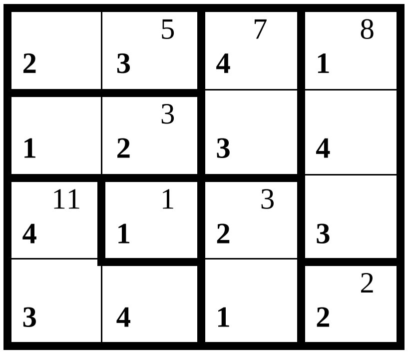
We'll help you solve this warm-up puzzle. Cover up our completed version to try it on your own!

WARM-UP PUZZLE



	A	B	C	D
1		5	7	8
2		3		
3	11	1	3	
4				2

ITS SOLUTION



2	5 **3**	7 **4**	8 **1**
1	3 **2**	**3**	**4**
11 **4**	1 **1**	3 **2**	**3**
3	**4**	**1**	2 **2**

(1) The single-box cluster at D4 must contain a 2. Where is the other such cluster, and what digit goes in there ?

(2) The three boxes in the upper right corner total 8. There are just three ways to achieve that: 134, 224,and 332, (in any order). But since you *can't* repeat a number in column four, two possibilities are eliminated! Such number logic will also let you set the bottom left-hand corner cluster of three boxes. Try it !

(3) Once three digits are in place in any row or column, the fourth must follow. It likely will not take you long to complete the puzzle.

Now for Chemical Ken-Ken. This time, it is a 5x5 grid, which makes it a bit harder. And this time, the given values are obtained by *multiplying*, not adding. For example, a three-box cluster containing 3, 3, and 5 would show a value of 45.

(By the way, note that that set of factors is the *only* way to get a three box cluster to have 45 as a value !)

In this blank grid we represent the value with a letter. Below the grid is a group of clues from the world of chemistry. As you decipher each clue, transfer that value to the grid, and then proceed as above. If “(Z)” appears at end of clue, enter that element’s *atomic number*. To help get started, the two single box clusters values are given directly.

a	2	b		c
	d			e
				f
		g	1	h
	i		j	

The clues:

a. The atomic number of PHOSPHOROUS.
b. Smallest of the noble gases. (Z)
c. This metal’s carbonate salt has a molmass of 100 amus. (Z)
d. The size of the charge of the STANNIC ion.
e. This metal burns with a brilliant white light, so sometimes is used in flares. (Z)
f. The metal used to *galvanize* iron. (Z)
g. Its electron configuration is [Kr] $5s^2$ $4d^2$. (Z)
h. This alkali metal has the strongest drive to be oxidized, measured by E_{ox} values. (Z)
i. The number of <u>neutrons</u> in the 1+ ion of Na-23 . (Z)
j. This elemental gas glows bright red when shocked. (Z)

Answers to the *ChemMatters* Puzzle

15 **3**	2 **2**	2 **1**	**4**	20 **5**
5	4 **1**	**2**	**3**	12 **4**
1	**4**	**3**	**5**	30 **2**
2	**5**	40 **4**	1 **1**	3 **3**
4	12 **3**	**5**	10 **2**	**1**

The numbers in the upper right corner of each cluster answer the 12 clues given.

NSES Correlation

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Recycling to Survive**	**Sewage**	**Drugs Down the Drain**	**Cleaning Up the Air**	**Kilimanjaro**
Science as Inquiry Standard A: about scientific inquiry.			✓	✓	✓
Physical Science Standard B: of the structure of atoms					✓
Physical Science Standard B: of the structure and properties of matter.	✓	✓			✓
Physical Science Standard B: of chemical reactions.	✓	✓	✓	✓	✓
Physical Science Standard D: of geochemical cycles				✓	✓
Science and Technology Standard E: about science and technology.	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.	✓	✓	✓	✓	
Science in Personal and Social Perspectives Standard F: about natural resources.	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: about natural and human-induced hazards.			✓	✓	
Science in Personal and Social Perspectives Standard F: about environmental quality.	✓	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✓	✓	✓	✓	✓
History and Nature of Science Standard G: of science as a human endeavor.	✓				✓
History and Nature of Science Standard G: of the nature of scientific knowledge.			✓	✓	✓
History and Nature of Science Standard G: of historical perspectives.				✓	✓

Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

Directions for all Anticipation Guides: ***Before reading***, in the first column, write "A" or "D," indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Recycling to Survive

Directions: *Before reading*, in the first column, write "A" or "D" indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Plastics are synthetic polymers with different types of structures.
		2. Many plastics are made from petrochemicals such as oil or natural gas.
		3. Most plastics are easily biodegradable.
		4. The recycling code on plastics refers to thermoplastics, the easiest kind of plastic to recycle.
		5. All methods of plastic recycling require similar input of energy and equipment.
		6. Recycled plastic can never be used for food containers.
		7. Physical recycling involves shredding plastic into plastic flakes.
		8. Recycling provides income for poor people in developing countries.

Is this Water Recycled Sewage?

Directions: *Before reading*, in the first column, write "A" or "D" indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Wastewater treatment plants remove bacteria and viruses.
		2. The first stage of wastewater treatment is based on physical properties of waste material, including solubility and density of the waste material.
		3. Bacteria are detrimental in all stages of the wastewater treatment process.
		4. The denitrification process removes only nitrogen compounds from the wastewater.
		5. Salts can be removed from wastewater by reverse osmosis.
		6. Red pipes are used internationally to identify recycled water.
		7. Recycled water has been used to re-supply dried-up geysers.
		8. There are some drawbacks to using chlorine to disinfect water.
		9. We have been able to keep recycled wastewater out of all major bodies of water in the United States.

Drugs Down the Drain: The Drugs You Swallow, the Water You Drink

Directions: *Before reading*, in the first column, write "A" or "D" indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Pharmaceuticals have been found in U.S. drinking water at doses up to one-tenth of the therapeutic dose.
		2. There is no evidence that dissolved pharmaceuticals harm fish.
		3. Wastewater treatment plants effectively remove pharmaceuticals from water.
		4. Detectable levels of pharmaceuticals, insecticides, and fire retardants are found in less than 50% of U. S. waterways.
		5. Chlorine can react with pharmaceuticals to form toxic compounds such as chloroform.
		6. Changing the pH level of water has no effect on the effectiveness of chlorine to remove some drugs.
		7. Activated charcoal filters and ozone remove many unwanted chemicals from drinking water.
		8. Ozone treatment continues to work even after water is treated with ozone.

Cleaning Up the Air

Directions: Before reading, in the first column, write “A” or “D” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	**Text**	**Statement**
		1. The temperature of Earth’s atmosphere has increased for the past 40 years.
		2. Plants remove CO_2 from the atmosphere during the day and release CO_2 at night.
		3. Photosynthesis adds CO_2 to the atmosphere and respiration removes CO_2 from the atmosphere.
		4. Human activities are not responsible for the increased atmospheric levels of CO_2.
		5. Water vapor and methane are greenhouse gases.
		6. The greenhouse effect is harmful to life on Earth.
		7. Carbon dioxide could be stored underground or in rocks with no additional energy costs.

Kilimanjaro: Peering through Disappearing Ice

Directions: *Before reading*, in the first column, write "A" or "D" indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Ice samples contain dust and bubbles of air that can provide information about past climate changes.
		2. All tropical glaciers are shrinking.
		3. The amount of methane and carbon dioxide in Earth's atmosphere is lower today than it was 25 000 years ago.
		4. Scientists who study ice cores work in room temperature rooms with their hands in freezers containing the ice cores.
		5. Water evaporates at the same rate from sea water, regardless of the isotope of oxygen in the water.
		6. Sublimation can cause ice to disappear.
		7. Water from Kilimanjaro is used for drinking and irrigation.

Reading Strategies

These matrices and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Recycling to Survive

Directions: As you read, please complete the charts below comparing the different types of plastic and how they are recycled.

	Thermoplastic	**Thermosetting**
Percent produced		
Examples		
How they are recycled		

In the table below, compare the different methods of recycling plastic

Method	**Process description**	**Advantages**
Physical Recycling		
Chemical Recycling		
Thermal Recycling		

Is this Water Recycled Sewage?

Directions: As you read, please complete the chart below describing the steps for recycling wastewater.

Step & Name	Description	Chemical Explanation
1.		
2.		
3.		
4.		

Drugs Down the Drain: The Drugs You Swallow, the Water You Drink

Directions: As you read, please complete the chart below describing why we should be concerned about drugs in our water, how drugs get into our water, and possible solutions to the problem of drugs in our water. Use bullets for each new idea.

Questions	*Provide at least two answers for each question.* *Use bullets or numbers.*
Why should we care about drugs in our water?	
How do drugs get into our water?	
How can we remove drugs from our water?	
How can we prevent drugs from getting into our water in the first place?	

Cleaning Up the Air

Directions: As you read, please complete the chart below describing the role of carbon dioxide in Earth's atmosphere.

	Description	**Advantages and Disadvantages**
Recycling carbon in nature		
The greenhouse effect and carbon dioxide		
Removing carbon dioxide from the atmosphere		

Kilimanjaro: Peering through Disappearing Ice

Directions: As you read, please complete the chart below describing how ice samples help us understand climate change. Use bullets for each new idea.

Ice core sample location	Challenges of obtaining samples	Climate change claims	Evidence for claims
Greenland and Antarctica			
Mount Kilimanjaro			

Recycling to Survive

Background Information (teacher information)

More on the history of recycling bottles

First recycle bill (for bottles only)

Recycling of plastics didn't happen on a large scale until several decades after plastics had become ubiquitous in our daily lives. It was only after people realized that the ever-increasing percentage of plastics in the huge amount of waste we were dumping in landfills would stay there for decades, and maybe centuries, that companies and municipalities saw the need for, and the opportunity to make money from, recycling.

The first recycling program (for any material) was the result of a law passed in 1971 in Oregon, called the "Bottle Bill". It involved placing a refundable 5-cent deposit on all beer and soft drink beverage containers, which at that time were mainly glass and aluminum. The bill originally was designed to cut down on litter along roadways and park paths. It was successful at this task in that it reduced the number of bottles in roadside litter from 40% of the total litter in 1971 to about 6% by 1979. (It was so successful that nine other states passed similar bills.)

Another goal of the bill was to promote the use of refillable bottles, in order to minimize the amount of raw material needed to produce new bottles and to reduce the amount of energy needed to manufacture the new bottles. Returning bottles meant they could be washed, sterilized and refilled, instead of throwing them "away". [Note: So, one might say, this wasn't a "recycle" bill at all, but a "reuse" bill. Reusing is actually preferable to recycling because it uses far less energy to reuse an object for the same purpose as that for which it was designed, as it would be to reprocess the material into a new object.]

From the Oregon Department of Environmental Quality website, *Oregon Bottle Bill: Then and Now*: "Refillable bottles were common prior to passage of the bottle bill. In 1971, about 36 percent of beer and 53 percent of soft drink bottles were true refillable bottles. Non-refillable bottles made up 31 percent of beer and 7 percent of soft drinks while cans made up 33 percent of beer and 40 percent of soft drinks. The immediate effect of the bottle bill was a sharp reduction in both cans and non-refillable bottles. Shortly after passage of the law, more than 90 percent of beer and soft drinks sold in Oregon were sold in refillable glass bottles." (http://www.deq.state.or.us/lq/sw/bottlebill/thenandnow.htm)

A gradual shift from local bottling plants to national production plants serving the whole country reduced the need and financial rewards of the refillable bottle. This is because it cost too much to transport refillables long distances to regional or national plants, reducing the profit margin considerably and opening the door for beverage manufacturers to lobby to return to non-refillable bottles.

A most noticeable effect of the bill has been the waste reduction aspect: since its inception, and ongoing, the bill has resulted in return rates in Oregon for beverage containers covered under the bill have exceeded 80%, with some years reaching 94%. Although rates have dropped back to 80% in recent years, the rates for other containers not covered by the bill are considerably lower, in the 36% range. Of course, 80% return means about 20% of bottles go into landfills and are unredeemed at the stores, which allows the store owners to pocket those refunds as profit.

Although only glass and aluminum were included in the original Bottle Bill, this was not because of the design of the bill, but because these were the only two materials used for beverage containers in 1971. The bill, however, did not state the composition of the container; it only said that it applied to beer and soft drink containers. That meant that when PET finally arrived on the scene about 10 years later, the bill was flexible enough to cover that material also. Eventually, PET bottles drastically outnumbered glass bottles in the refundable-deposit bottle arena.

The Oregon Bottle Bill lasted in its original state until 2007. It was not the advent of plastics that caused its eventual change, rather the bill was expanded in 2007 to include water and flavored water containers, drinks that hadn't even been "invented" way back in 1971. Interestingly enough, the expanded bill wasn't as all-encompassing as the original bill, as it failed to include teas, juices and other new beverages, containers of which now litter roads, since they have no deposit requirements, and thus no value to consumers. The deposit fee remained 5 cents in the expanded bill, even though a nickel in 1971 would now be worth about 26 cents.
(Oregon Department of Environmental Quality's Bottle Bill webpage:
http://www.deq.state.or.us/lq/sw/bottlebill/index.htm)
(Oregon.gov's Bottle Bill & Redemption Center Info webpage:
http://www.oregon.gov/OLCC/bottle_bill.shtml)

The idea of widening the net of states that have "bottle-bill" legislation apparently is not dead. The "Bottle Bill Resource Guide" is a web site dedicated to increasing the number of states that legislate a deposit-refund system to greatly increase the recycle rate of plastic, glass and aluminum beverage containers. (http://www.bottlebill.org/)

More on recycle codes

As noted in the article, the waste stream of plastics contains many different types of plastics, each of which must be processed separately from the rest, in order to ensure the integrity of the resulting recycled plastic. Recognizing this growing problem, in 1988 the Society for Plastics Industry (SPI) issued the now-familiar plastics recycling code (although they call it the resin recycling code). The goal of the code, now recognized internationally, was to make it easier for the public to recognize the various types of resins, to make it easier to separate the various high-volume polymer types from the comingled waste stream—to make recycling easier for all (and therefore more probable and more profitable).

For more information on the Society for Plastics Industries recycle code, directly from SPI, see http://www.plasticsindustry.org/AboutPlastics/content.cfm?ItemNumber=823&navItemNumber=2144. A short 4-minute video explains the recycle code numbers 1-6 and provides a bit more about the meaning of recycle code 7.

More on recyclable plastics

The first 2-liter bottles

In the interest of reducing the amount of plastic going into landfills in the first place, the plastic bottle industry did much research in the early days of PET bottle manufacture into reducing the weight of the 2-liter soda bottle (and other PET bottles as well). Original 2-liter PET bottle molds formed a round-bottom bottle. That needed a stabilizer cup glued to the bottom of the bottle to help them stand up. This cup was made of a different polymer, most likely polyethylene. This, of course, added cost to the bottle, requiring two separate pieces of plastic, and dabs of glue to hold the two together. They were able to eliminate the need for the bottom stabilizer cup that first appeared on plastic soda bottles by including in the molds for the bottles five small indentations in the bottle itself, making feet" to stabilize each bottle.

This also eliminated the second type of plastic from the waste stream, making it easier to recycle PET bottles. It also reduced the weight of the bottle. From 1980-1995, over 15 years, the PET plastic bottle industry was able to lower the total mass of the PET in two-liter bottles from 68g to 48g, according to the National Association for Plastic Container Recovery (NAPCOR).

Polystyrene recycling

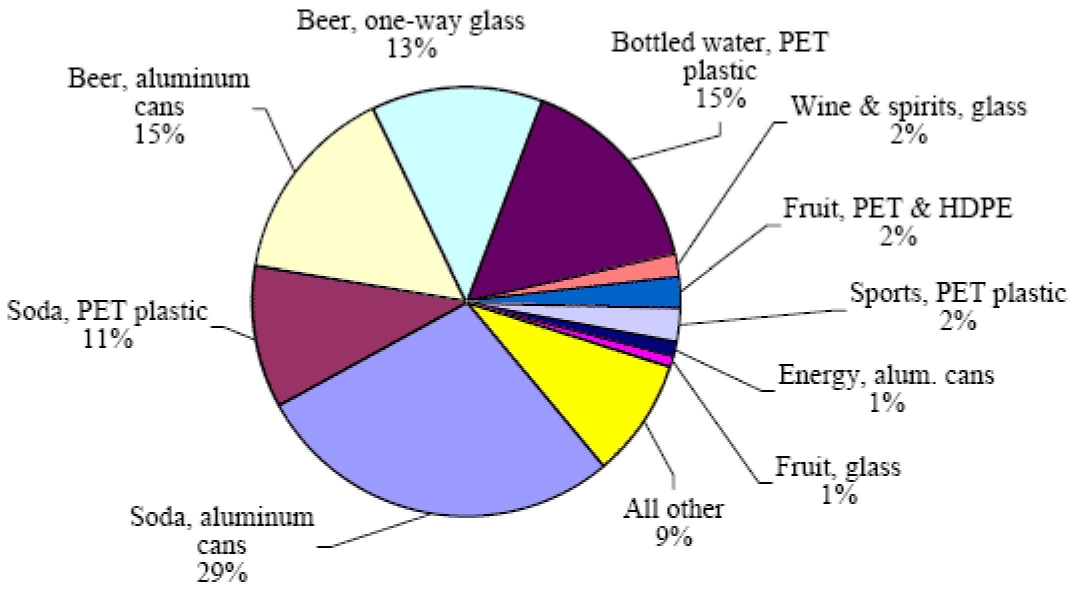
Most municipal recycling systems do not include polystyrene (PS, #6 recycle code). There are several reasons for this. The first is that much polystyrene waste is expanded polystyrene, EPS. This is plastic that has a blowing agent added to it in processing so that the actual plastic contains closed cells that contain gas from the blowing agent that was produced with the heating and processing of the resin and resulted in the bubbles forming in the plastic. This blowing agent used to be CFCs, until they were outlawed by Federal regulation. The blowing agent of choice now is pentane, although for food packaging containers the agent is carbon dioxide. The density of “normal” polystyrene, the plastic is about 1.05 g/cm^3. The density of expanded polystyrene, EPS, is very low, from 0.016-0.64 g/cm^3. When recycling firms discuss the amount of PS recycled, they will typically say that the mass of PS in the municipal waste stream (MWS) is extremely low, about 1% of the total waste. But that hides the fact that the volume of polystyrene in the waste stream is much larger, since its density is so low. This large volume is difficult to handle in a municipal waste stream and adds much bulk to the waste collected, while adding little actual material (plastic) and thus little financial value.

A second reason for PS not being included in recycling programs is that there is almost no secondary market for recycled PS, resulting in a low resale value for recycled polystyrene. This is a bit of a “catch-22” since, if there were a secondary market, that would raise the scrap Value of PS, and that in turn would encourage more municipalities to recycle PS to provide more income.

Recycling statistics

The Container Recycling Institute maintains databases to show the production, use, recycling and wasting of PET vs. aluminum cans and steel cans. The graph below shows the production share for each of the categories noted. Note that aluminum cans, both soda and beer, account for almost half the total beverage container market. Note also that production of PET bottled water containers now (2006) outnumbers PET soda bottle production.

Market Share by Beverage and Package, 2006



© *Container Recycling Institute, 2008*

http://www.container-recycling.org/facts/all/data/marketshare.htm

More on plastics in a landfill

Trash bags or grocery bags are made of polyethylene. In attempts to make them biodegradable, scientists have added corn starch to the plastic. Corn starch will degrade in the presence of air and water, so adding some to the plastic should make it more degradable over the long term. According to Dr. Ramani Narayan, a researcher at the Michigan Biotechnology Institute in Lansing, these experiments have met with limited success.

> For very strong, very stiff trash bags, cellulose or woody materials can be used," he says, "but if you want a cheaper, more biodegradable trash bag material, and are willing to sacrifice some strength, then cornstarch can be used." Presently [1991], most biodegradable trash bags contain around 6% cornstarch. Some bags contain 30-60% cornstarch.
>
> In a six-month study, chemist Michael Tempestra at the University of Missouri in Columbia exposed polyethylene films, with and without 6% starch, to conditions simulating a landfill, a compost heap, an anaerobic (without oxygen) waste-treatment plant, and surface litter. His findings showed the starch was removed from the polyethylene in all these environments, and that the polyethylene degraded to smaller molecules of waxy materials. However, the extent of the degradation was unpredictable-sometimes the samples lost a lot of polyethylene; other times very little.

(Downey, C. Biodegradable Bags *ChemMatters*, October, **1991**, *9* (1), pp 4-6.)

It appears more work was necessary at that time.

More plastics today are being made to be degradable. Biodegradableplastics.org's website contains information on biodegradation and photodegradation, as well as bioplastics and composting, a newer mechanism for degrading plastics that is designed to keep them out of landfills. For another take on the story of biodegradability, see "Biodegradable Plastics: True or False? Good or Bad?" on the sustainableplastics.org website at http://www.sustainableplastics.org/spotlight/biodegradable-plastics-true-or-false-good-or-bad. It shows 6 companies' claims of their products' biodegradability, but calls into question the actual properties of the products. (Of course, you should note that the goal of sustainableplastics.org is to manufacture biodegradable plastics, so they have a vested interest in making petroleum-based plastics look bad.)

Yet another website, mindfully.org, has prepared a brief fact sheet describing three generations of starch-based plastics. The first plastic bags made with starch contained only 5-20% starch, and were not very biodegradable, since they still contained 80% synthetic polymer material (probably polyethylene). Second generation starch-based plastics contained larger amounts of starch (50-80%), and the starch was actually incorporated into the plastic, making it more biodegradable, but still not completely so. The third generation is actually 100% starch-based biopolymeric plastic. See the site at http://www.mindfully.org/Plastic/Biodegradable-Plastic.htm.

More on thermoplastics and thermoset plastics

Thermoplastics are typically solids at room temperature, but will melt or become soft when heated. At these higher temperatures, they can be molded into useful objects that retain their shapes when cooled again. Thermoplastics are usually linear or slightly branched polymer chains. As such, when heated they do not chemically bond with each other, but instead the long chains are attracted to each other by van der Waals forces. These weak forces cause the chains to clump together and entangle one another, like a clump of cooked spaghetti strands.

If heated again to the same higher temperatures, they will re-melt and can be re-molded, over and over again. When heated, the long polymer strands slide past one another (called plastic flow) and they tangle around one another (due to increased molecular motion). Weak van der Waals forces arise between adjacent atoms on juxtaposed polymer strands. Once cooled, these forces maintain the entanglements to hold the long strands in place, and the object maintains its shape—so long as the plastic is not heated sufficiently to once again agitate the polymer chains, weakening the effect of the van der Waals forces, enabling the chains to move and realign once again.

It is this ability to be heated and re-molded that makes thermoplastics so valuable in the recycling industry, as they can be collected, processed, heated and reformed into new useful objects. Some degradation of the polymer does occur, however, after each reheating and cooling, so thermoplastics cannot be recycled indefinitely. That is why virgin resin is often added to recycled plastic in processing—to increase its strength and durability. You can read more about the characteristics of thermoplastics at Wikipedia: http://en.wikipedia.org/wiki/Thermoplastic.

Thermosetting plastics (thermosets—[set with heat], for short) are soft solids, or even liquids, at room temperature. They are sometimes considered to be pre-polymers. However, at higher temperatures they will melt and become malleable. At these high temperatures (generally above 200°C) they will form crosslinks between the long polymer strands, forming a three-dimensional network of polymer molecules. These crosslinks are permanent chemical bonds, not just intermolecular (secondary) bonds (as in thermoplastics). When molded and then cooled, the polymer strands are held by the crosslinks; they are said to be “cured”, as in curing rubber (also a thermoset). Usually a curing agent is needed to serve as the permanent crosslink between polymer strands.

These thermoset plastics are locked in that shape permanently. Upon reheating to the same high temperatures as before, they will not melt because the crosslink chemical bonds that formed the first time still remain in place. During the formation of the crosslinks between polymer strands in the first heating, the polymer itself became larger molecules, resulting in higher melting temperatures than the pre-polymer. Thus reheating the plastic to its original melting temperature will have no effect on the plastic. Further (higher temperature) heating will only result in the degradation or charring of the thermoset.

The permanence of thermosets makes them practically useless in recycling efforts because there is no after-market for these materials. Their only value might be as a fuel, since they are still primarily hydrocarbons and will therefore still burn. Gases produced from the burning of thermosets then become a problem for industries using them for fuel.

This table, from a NASA publication, shows some of the differences between thermoplastics and thermosets.

Thermoplastics	Thermosets
• Description – Melt, flow and cool polymer matrix into final shape – Remeltable	• Description – Mix and flow resin, and curing agent – React to form polymer matrix with final shape – Crosslinked, cannot be melted
• Advantages – Directly recyclable with some loss of properties – Shorter cycle time	• Advantages – Higher use temperatures – Paint online with steel
• Disadvantages – Dimensional stability at high temperatures – Paint offline	• Disadvantages – Secondary recycling
• Examples: Nylon, PPS, PEEK, [PE, PET]	• Examples: Polyurethanes, epoxies

(http://www.tpub.com/content/nasa2001/NASA-2001-cp211029/NASA-2001-cp2110290563.htm)

More on the methods of recycling of plastics

As mentioned in the article, physical recycling, also called mechanical recycling, involves collection, sorting, chopping, washing, heating, and remolding or re-spinning the plastic (into fiber). These are physical changes in the material, and at the end of the process we have essentially the same material as we had at the start of the process.

Chemical recycling can be done in one of four ways:

- Pyrolysis, where plastic waste is heated to very high temperatures in a vacuum to produce a mixture of gas and liquid hydrocarbons that are not unlike crude oil before its processing
- Hydrogenation, where plastic waste is heated (again, to very high temperatures) with hydrogen, which results in "cracking" of the polymers into a liquid hydrocarbon
- Gasification, whereby plastic waste is heated in air, which results in a mixture of carbon monoxide and hydrogen gases. These are then used to prepare new raw materials, such as methanol, which can also be used as a fuel.
- Chemolysis, whereby individual plastics are treated chemically or de-polymerized and returned to their original monomers. (This is the process described in the article.

  Any of the above four processes involves changing the plastic chemically into new substances; hence the term, chemical recycling.

(http://www.plastics.org.nz/factsandresources/schoolsresources/wasteandrecyclingfacts/)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic chemistry**—The ability of carbon to form multiple bonds—with itself and with other elements—is the reason for the existence of polymers.
2. **Petroleum chemistry**—It would be good for students to understand how versatile a mixture crude oil is as a feedstock for many industries, and that mankind shouldn't be using it solely as a fuel in cars (gasoline) of furnaces (fuel oil).
3. **Polymers**— Although polymers don't usually show up in a typical chemistry curriculum until near the end of the year, if at all, the ubiquity of polymers in our lives makes this a topic of high interest for students.
4. **Secondary (intermolecular) bonding**—While individual secondary bonds are not very strong (think dipole-dipole interactions or van der Waals forces), the huge number of intermolecular bonds involved in macromolecular polymer molecules accounts for many of the properties of polymers.
5. **Reversibility of reactions**—The chemical method of recycling shows that some types of polymerization reactions can be reversed. Information in the "More on chemical recycling" can be used to discuss the feasibility of doing this type of reaction, in terms of energy consumption. The reversibility of these reactions could lead to a discussion of equilibrium.
6. **Sustainability**—Recycling is a major way we can avoid using up all our natural resources
7. **Industrial chemistry**—Students don't often get a chance in high school chemistry to see chemistry related to industrial plants. This would be a good time to discuss chemistry's central role in manufacturing all the goods students use/consume every day.
8. **Phase changes**—Thermoplastic molding is a phase change from liquid (heated) to solid (cooled). It involves only intermolecular bonding, so it is a physical change. Thermosets also involve a phase change from liquid (heated) to solid (cooled), but this is both a physical change and a chemical change, because primary chemical bonds—crosslinks—form between the polymer strands, forming a much larger polymer molecule.
9. **Physical changes vs. chemical changes**—see 8 above. Physical changes are easily reversible—thermoplastics can be heated and reform the solid; chemical changes are not easily reversible—thermosets cannot be heated and reformed. Also, physical vs. chemical recycling also illustrates these differences between physical and chemical changes.
10. **Safety**—The hazards of recycling might provide a good opportunity to discuss safety in both industry and lab settings.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"All plastic is the same, right?"** *Actually, students should already know this isn't true, if they take a moment to look closely at some of the plastics around them. Transparent plastic wrap looks nothing like a translucent milk jug, for instance, even though they are similar chemically. A flexible, transparent water bottle doesn't have any of the properties of a piece of rigid, opaque PVC (polyvinyl chloride) pipe. Each type of plastic has its own set of unique properties that make it better for some purposes than for others.*
2. **"When the guys take my plastic stuff for recycling, they just throw the whole pile together and melt it down to make new stuff."** *As the article mentions, in order to recycle, the first thing the processing plant has to do is to sort the plastic material into different piles based on the recycle code of the plastic. A mix of plastics melted down would result in a plastic that is of very little use because it would have a mix of properties of the individual plastics—and none of their strengths.*
3. **"Polymers are all plastics; plastics are the only polymers."** *Plastics are only a small segment of the polymer "population". In synthetic polymers, there are also films (e.g., plastic wraps) and coatings (e.g., paints), fibers (e.g., nylon, Spandex, etc.) adhesives (e.g., superglue and hair spray) and elastomers (e.g., tires and balloons). Natural polymers comprise almost all living matter; e.g., DNA, proteins, cells, tissue, organs, etc. There are also natural films and coatings (e.g., "milk" from milkweed), fibers (e.g., cotton and wool), adhesives (e.g., barnacle secretions), and elastomers (e.g., natural rubber from rubber trees).*
4. **"All plastics 'live forever'—there aren't any that degrade quickly or easily."** *While most plastics do have long lives, some plastics are purposely manufactured to degrade quickly, either by action of bacteria (biodegradable, or light (photodegradable). For example, six-pack rings from cans of carbonated beverages were required to be made photodegradable by ultraviolet light (from the sun) in Federal law* 40CFR238.30, in order to protect fish, birds and other wildlife. *(*http://edocket.access.gpo.gov/cfr_2003/julqtr/40cfr238.30.htm)
   Other plastics have been made to be biodegradable, upon exposure to moisture, air and bacteria. The problem with this is that most plastic is buried in landfills, where air is not abundantly available, so biodegradation is still a slow process in these conditions.
5. **"We made a polymer in class today—we made 'slime'."** *"Slime" is indeed a polymer, but you didn't make it a polymer—it already was a polymer. "Slime" is made of polyvinyl alcohol and borax, or Elmer's glue and borax; however, the polymer was already there in the original reactants—polyvinyl alcohol is a polymer and Elmer's glue contains polyvinyl acetate; again, already a polymer. The addition of borax solution to either of these polymers merely cross-links the polymer chains to make the whole entity less fluid and not as flexible, to make into "slime".*
6. **"So, if we recycle all our plastics, we'll never run out of raw material to make new stuff."** *That would be really great. Unfortunately, each time we recycle a plastic item, the plastic degrades a bit and loses some of its desirable properties. That's why companies using recycled plastic will typically add some virgin resin (plastic) to the recycled material, to help maintain the original properties. There is a limit to how often plastic can be recycled.*

Anticipating Student Questions (answers to questions students might ask in class)

1. **"Why don't we recycle polystyrene (Recycle code #6)?"** *See "Polystyrene recycling" under "More on recyclable plastics" above.*
2. **"What do the recycle code numbers mean?"** *The article shows you what each type of plastic is, according to the recycle code numbers. The numbers themselves were established based on the volume of each type of plastic in the waste stream. PET (or PETE) was the most used—and discarded—plastic at the time the recycle code was established. The thinking was that the most used and discarded plastics would be the most logical ones to recycle since they would likely provide profit due to their higher volume for recycling and to their after-processing resale value.*
3. **"Why don't thermoset plastics soften when heated?"** *Cross-links between polymer strands are not easily broken. Heat causes increased molecular motion in polymers (as in all material), but the heat is as likely to break bonds* ***along*** *the polymer strands as it is to break the bonds in the cross-links. This results in shorter strands in the polymer, which destroys the integrity of the polymer. The long strands can't be easily reformed to restore the polymer to its original condition. In a thermoplastic, heating breaks the weaker intermolecular bonds between the strands, but most of the strands themselves remain intact, and when the heated plastic is remolded and cooled, the attractions between the unchanged strands can re-establish themselves and restore the plastic to close-to-its-original condition.*
4. **"If we can produce PET indistinguishable from the original virgin PET by chemical recycling, why don't we do it for all the plastics? That way we'd never run out of plastic."** *While this is logical from a materials point of view, what is missing from this equation is the chemical needed (methanol) to make the reverse reaction happen, the heat and pressure (both energy-intensive) needed to make it happen, and the machinery needed to make it happen. It is a very expensive process. Perhaps someday we will come to the point where we will have to do this reverse polymerization process because we have no more raw materials from which to make new plastic, but by then materials will be very expensive, indeed.*
5. **"Why don't we have small-scale recycling here in the US, like in India?"** *First, it is very labor-intensive, as well as energy-intensive. It takes a lot of energy (fuel) to collect the plastic for recycling (think how much energy it would take if we each drove our waste to a small-scale recycling facility, instead of having one truck come and pick it all up for all of us), and it takes a lot of energy to run the machinery. It is more energy- and labor-efficient to centralize the process in a large-scale plant. Second, as you can see from the article, there are serious health hazards to humans associated with the small-scale recycling operations in India and elsewhere. Our government regulations would never allow people to be exposed to the machinery and dust, etc. Our large-scale operations are automated, in part, to avoid human exposure to these hazards, and they contain the dust so that it is not released into the atmosphere.*

In-class Activities (lesson ideas, including labs & demonstrations)

1. Recycle PET into fibers by heating a small piece of a 2-Liter PET soda bottle (or smaller PET bottle) on a piece of aluminum foil on a hot plate and use a wooden splint to draw the molten PET info long fibers. You can find the write-up for the activity at the Macrogalleria website, http://pslc.ws/macrog/demos/recycle.htm, or at the Polymer Ambassadors website,

http://polymerambassadors.org/fibers.pdf. The Polymer Ambassadors page also includes a simulation of ram extrusion of plastic involving polyvinyl alcohol in a syringe, injected into acetone.

You can view this YouTube video to show the industrial process of recycling PET from bottles into fibers and cloth: http://www.youtube.com/watch?v=zyF9MxlcItw&feature=related.

2. The American Chemistry Council has an updated version of their "Hands on Plastics" kit for middle/high school students. It contains samples of the major plastic resins from the recycle codes, a PET pre-form and a sample of plastic lumber recycled from milk jugs, as well as lesson plans to cover several topics in plastics, including a lab to separate and identify the six major recyclable plastics. The site below gives a good description of the kit, as well as online access to the teacher materials and 8 short videos for students. The kit costs $12.99 and can be ordered online at http://www.americanchemistry.com/store/detail.aspx?ID=259&CategoryID=14&ProductType=-1&ParentID.
3. To show how many PET bottles we recycle in the US daily—and how many bottles are discarded—see this animated video, "Animated Water Bottle Recycling Rates": http://www.youtube.com/watch?v=OZbTXDkrD1o. It shows a "trickle" of bottles being recycled, and then a "waterfall" of bottles being discarded, a bit of an eye-opener.
4. To show that recycling of plastics isn't the "only game in town", you might want to have students try their hand at recycling paper. See "Making and Sizing Paper" on the Chemical Heritage Foundation's "Science Alive!" website at http://www.chemheritage.org/percy-julian/activities/6a.html. Click on the "For Teachers" button at the top to access background material and alignment with National Standards.

   The Fun Science Gallery website has a section called "Making and Recycling Paper at Home" that describes the paper-making process in detail, and has nice photos to support the steps in the process. It also discusses a bit of recycling of paper at the end. The site also discusses a bit of the history of paper before the paper-making activity, and it gives a brief web bibliography of paper-related sites. View it all at http://www.funsci.com/fun3_en/paper/paper.htm#3.
5. The Cornell Center for Materials Research provides a series of polymer activities for high school students and teachers, called "Polymer Investigations". It consists of a series of four days of class activities that could be used as part of a unit on organic chemistry, or on a short unit just on polymers. The activities include drawing fibers from plastics, as noted in 1) above, as well as an introduction to polymers, and conducting trash audits to discover more about recycling. Teacher information and student investigation forms are all available at http://www.ccmr.cornell.edu/education/modules/documents/PolymerInvestigations.pdf. Student work includes extensions involving research and group presentations on the uses and disposal of petroleum-based and/or bio-polymer materials.
6. You can have students study the effects on various plastics of being buried in a landfill for a class experiment. Here is a site that uses this topic as a science fair project for students. It suggests allowing at least three months to complete the project. It deals with paper bags, plastic bags, and newspaper. (http://www.education.com/science-fair/article/biodegrade-plastic-paper-newspaper/)
7. Although the following web site is from a PBS video that focused on recycling of the Trabant, a Russian car, it contains two activities that simulate 1) sorting materials from a mixture of waste for recycling and 2) a landfill. Each gives students a bit better idea of these two processes that municipal waste managers face in their daily routine. The level is probably middle school, but the ideas are relevant to high school. The sorting activity uses static electricity, magnetism, density, coefficient of friction and air pressure to separate materials. (http://www.pbs.org/safarchive/4_class/45_pguides/pguide_402/4542_trabant.html)

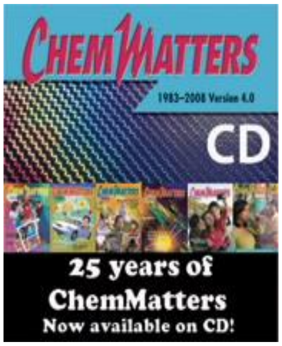
8. You can show the difference between thermoplastics and thermosetting plastics using craft store materials. Friendly Plastic® and Sculpey® III are two materials available in most craft/art stores. Friendly Plastic® is a thermoplastic, which is fairly rigid at room temperature, but it can be heated and then molded into a specific shape, and when it cools it will retain that shape. Sculpey® III is a thermoset; it is a polymer clay that is soft and can be shaped at room temperature, but when baked ("fired") in an oven, it becomes rigid, just like fired natural clay. Upon reheating, the Friendly Plastic® can be re-shaped (thermoplastic). The Sculpey® III is permanently held in its baked shape; further heating will not change the Sculpey® III (thermoset).
   (http://www.amaco.com/shop/product-430-friendly-plastic-pellets.html)
   (http://sculpey.com/products/clays/sculpey-iii)
   A lesson plan for a student activity using these materials can be found at http://www.midmichiganspe.org/pdfs/documents/thermoplasticandthermoset.pdf. This activity also uses two-part epoxy putty as another example of a thermoset plastic. The instructions give teachers a few pieces of background information, including mention of polycaprolactone and its unavailability at the time of writing the activity. That is not true now (2010); it is available as Friendly Plastic®.
   The MSDS for Friendly Plastic® can be found here: http://cdn.dickblick.com/msds/DBH_60602XXXX.pdf. It does NOT give its chemical name or formula, but Wikipedia states that Friendly Plastic® is one of several trade names for polycaprolactone.
9. Glencoe publisher has a WebQuest project on recycling plastics for its middle school book *Physical Science.* You could take this idea and expand on it as a way to cover the topic of recycling plastics (or for the topic of polymers) in a controlled assignment, without spending much class time teaching the topic. (http://glencoe.mcgraw-hill.com/sites/0078779626/student_view0/unit5/webquest_projects.html)

Out-of-class Activities and Projects (student research, class projects)

1. Students can research the various projects dealing with plastics recycling in underdeveloped countries. They might begin with "More sites on recycling in other countries", below:
2. Students could prepare a class report on the current state of plastics recycling in the US. The class might collect and display examples of materials from the six major categories.
3. Students could contact a recycling facility in your area and find out how the 6 types of plastics are sorted and processed. They could also research the aftermarket for these recycled materials: After the plastics are sold, what are some of the products manufactured from the recycled plastic? Then they could find examples of these products and make a list of their properties and uses and report to the class their findings. (from *ChemMatters* Teachers Guide, October, 2000.)
4. Students might want to investigate the paper vs. plastic shopping bag controversy to see which is better for the environment—and the economy, remembering to include recycling in their analysis.
5. Students might want to research the PET bottle vs. aluminum can scenario to see which is better for the environment and the economy, remembering to include recycling in their analysis. (See "Bottles or Cans?", *ChemMatters*, October, 2000 p 11, for some ideas.)
6. Students could bring in samples of each the 7 recycle code plastics and describe the properties of each type of plastic, as well as their relative recyclability, based on research the students do on the internet.

References (non-Web-based information sources)

Teegarden, D. *Polymer Chemistry: Introduction to an Indispensible Science*; NSTA Press, National Science Teachers Association, Arlington, VA, 2004. (NSTA member price: $27.95; non-member, $34.95.) NSTA has published a very comprehensive polymer chemistry book for teachers. Its 10 chapters cover the topic very well. It includes a section for demonstrations and experiments for students to do. The author also discusses how the book can be used in a chemistry class. The book includes a chapter on recycling, degradability and disposal of polymers.



The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for $30 (or a site/school license is available for $105) at this site: http://www.acs.org/chemmatters. (At the bottom of the Website screen, click on the *ChemMatters* CD image like the one at the right.)

Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Plummer, C. PET Recycling: It's Not Easy Getting New Shirts from Old Bottles. *ChemMatters*, October, **1994**, *12* (3), pp 7-9.
Plummer's article details the recycling process for PET into fibers. It also includes the original "Making and Unmaking of PET" sidebar describing the chemical recycling process for PET that appears in the present article.

Downey, C. Biodegradable Bags *ChemMatters*, October, **1991**, *9* (3), pp 4-6.
Downey describes scientists' attempts to make bags biodegradable by adding starch molecules at varying sites along the main polymer chains, to aid digestion of the chains by microbes.

Wood, C. Dissolving Plastic. *ChemMatters*, October, **1987**, *5* (3), pp 12-15. The article describes the production and use of polyvinyl alcohol laundry bags, used in hospitals to contain biohazardous laundry. The PVA bags are soluble in hot water. This is one plastic/polymer we don't have to worry about in the general waste stream!

Black, H. Putting a High Grade on Degradables. *ChemMatters*, April, **1999**, *17* (2), pp 14-15. The article focuses on polylactic acid. PLA, is made from corn and other starches, and will biodegrade over time. This would reduce the need for recycling.

Washam, C. Plastics Go Green. *ChemMatters*, April, **2010**, *28* (2), pp 10-13. Author Washam describes bioplastics, made from natural sources—sugar from corn and, in other countries, from sugarcane, sugar beets, wheat or potatoes. These plastics are designed to be more environmentally friendly as they are biodegradable, so that should keep them out of landfills. But there's more to that story—in the story. The April, 2010 issue is too new to be in the 25-year CD, but it is available free online at http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_SUPERARTICLE&node_id=1090&use_sec=false&sec_url_var=region1&__uuid=5da6cbb4-7c05-4307-833f-

5d18b8b1dc6d. Click on “Past Issues and Teacher’s guide” at the bottom of the screen. Then click on the April, 2010 issue icon, and finally on “Plastics Go Green”, a pdf file.

Websites for Additional Information (Web-based information sources)

More sites on recycling

The obviously.com website sports the “world’s shortest comprehensive recycling guide” at http://www.obviously.com/recycle/guides/shortest.html. Its concluding statement: “Unless you buy recycled products you are not recycling.”

Here is a 2010 article about Nantucket, Mass, and how they are not only recycling all their waste, but they’re actually mining their old landfill to reduce the trash that’s already there! (http://www.plasticsnews.com/headlines2.html?id=17891&channel=270)

Plastics News has a website that contains an archive of articles on recycling that goes back to 2007: http://www.plasticsnews.com/blog/recycling/.

More sites on the recycling industry

A 110-page book in pdf form on plastic waste management/recycling facilities in underdeveloped countries can be found at http://www.waste.nl/content/download/284/2234/file/UW2%20PLASTIC%20ebook.pdf. It contains many photos of smaller-scale machinery in use to recycle plastics.

The Container Recycling Institute, CRI, website contains large number of graphs showing the relative rates of US production, recycling and wasting of PET bottles vs. aluminum vs. steel cans at http://www.container-recycling.org/facts/data.php?materials=plastic.

The Plastics Division of the American Chemistry Council contracted a firm to do a study on the total energy, raw material needs and waste production involved in the manufacture of various plastics, from virgin material and from recycled material. You can find this extensive 2010 report, *Life Cycle Inventory of 100% Postconsumer HDPE and PET Recycled Resin from Postconsumer Containers and Packaging*, at http://www.container-recycling.org/assets/pdfs/plastic/LCA-RecycledPlastics2010.pdf. The file contains tables of data and charts to document the group’s findings, including consideration of the energy needs and greenhouse gases produced by the various methods in the report.

NAPCOR has published the “2009 PET Rate Report”, detailing usage of PET for the last 10 years. You can view it at http://www.plasticsrecycling.org/news/news-archives/8-news-archives/104-2009-pet-rate-report.

More sites on recycling codes

The American Chemistry Council provides a pdf file of information about the SPI recycle codes, the types of plastics, their properties, uses, and products made from the recycled resin.

The file, “Plastic Packaging Resins,” is available at http://www.americanchemistry.com/s_plastics/bin.asp?CID=1102&DID=4645&DOC=FILE.PDF.

More sites on plastics

The American Chemistry Council website has a page, the Plastics Learning Center, that contains single-page information sheets about lots of topics concerning plastics at http://www.americanchemistry.com/plastics/sec_learning.asp?CID=1102&DID=4256.

SPI, the plastics industry trade association, has a website that offers much information about plastics and recycling, along with lots of information just for people in the industry. View the site at http://www.plasticsindustry.org/.

More sites on types of plastics

An extensive coverage of the polymer resin polyethylene terephthalate, PET, including physical and chemical data, can be found at “the full wiki”, http://www.thefullwiki.org/Polyethylene_terephthalate#Polyester_recycling_industry.

The American Chemistry Council website contains a page of frequently asked questions (FAQs) about polystyrene (PS, #6 on the recycling code system) at http://www.americanchemistry.com/s_plastics/doc_pfpg.asp?CID=1417&DID=5332.

More sites on thermoplastics and thermosets

NPI, a resin providing industry, has a one-page fact sheet on the differences between thermoplastics and thermosets, as well as a description of several different processing methods for making plastics. (http://www.npiplastic.com/thermoplastics.htm)

“Basic Polymer Chemistry, Part 2” is a slide show of sorts with 19 slides describing properties of polymers. The slide mechanism is a bit disconcerting, and there are ads with each slide. Nonetheless, it includes diagrams of polymer chains that may help students visualize what the chains look like, especially thermoplastics and thermosets. (Unfortunately, I can’t locate Part 1 on the web). You can find Part 2 at http://www.scribd.com/doc/25358409/Basic-Polymer-Chemistry-Part-2.

More sites on reducing—before (or instead of) recycling

A video produced by *ChemMatters* - Episode 2: “Plastics Go Green” deals with bioplastics, a way to avoid putting plastics into the municipal waste stream in the first place, thereby reducing the need to recycle plastics. It’s projected that as much as 20% of plastics (total produced: 200,000,000,000 lbs / year) could be replaced with bioplastics within 10 years. See the 8:30 vimeo video at http://vimeo.com/11077939.

You can find a 34-slide presentation, “Biobased and Biodegradable Plastics 101” from Michigan State University, describing degradability and biodegradability and global standards for these at http://www.plasticsindustry.org/files/events/pdfs/bio-narayan-061906.pdf.

More sites on PET bottle manufacture

“How Plastic Bottles are Made”, on YouTube at http://www.youtube.com/watch?v=T01i_vp2mJE, shows the mechanized process of making PET bottles. It includes several mentions of recycled material as it shows the addition of recycled PET flake to the virgin PET pellets to make 10% recycled plastic bottles. It also mentions at the end that the recycled resin that bottle plants use doesn’t come from recycled bottles, but from leftover new plastic from its manufacturing process.

An animated silent version of the blow-molding process shows the insides of the blow-molding machinery. YouTube has it at http://www.youtube.com/watch?v=vSabFFQUr9E&feature=related.

More sites on recycling in other countries

There are lots of videos on YouTube showing recycling efforts in various underdeveloped countries:

Recycling plastic bags into fence posts in Nairobi, Kenya, “Plastic Bag Recycling in Kenya”: http://www.youtube.com/watch?v=IFq3EoxJg3A

“Plastic Recycling in Bangladesh”: http://www.youtube.com/watch?v=kF8OznRoWAU&feature=related

“China’s Growing Recycling Industry”: http://www.youtube.com/watch?v=wdIeUev22qM&NR=1&feature=fvwp

As a follow-up to the previous video, this one shows that UK exports its waste to China for processing there, instead of taking care of it themselves. (The US does the same thing.) See “UK Rubbish Exported to China” at http://www.youtube.com/watch?v=E4r3krs8eEY&NR=1.

There are also LOTS of videos showing animals dying from becoming entangled in plastic, or from eating plastic. (I won’t share videos of these; you can find them easily enough.) This does speak to the need to get plastic out of the waste stream and into recycling programs.

There are also videos on debris in the oceans. See, for example, “Destroying Planet Earth: The Great Pacific Garbage Patch” from the TV show, “Good Morning America”. (http://www.youtube.com/watch?v=OFMW8srq0Qk&NR=1)

General Web References (Web information not solely related to article topic)

Plastics New Zealand’s website has a wealth of information about plastics and the plastics industry, including information about recycling.

(http://www.plastics.org.nz/factsandresources/typesofplastic/materialfactsheets/?PHPSESSID=43825a1734bae3f02a371421d7fdf03d)

Plastics Wiki is a web site, similar to Wikipedia, just for polymer information. You can find just about anything you'd ever want to know about plastics at this site: http://www.plasticstech.info/processes/.

Plastics News has a very extensive website dealing with all aspects of plastics. Its primary audience is people in the plastics industry, but teachers and students can find a wealth of information on the site. The search feature allows you to search in their database for any polymer-related topic. (http://www.plasticsnews.com/)

More Websites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

You can find a 44-slide Power Point presentation covering the basics of polymers at http://www.csun.edu/~bavarian/Courses/MSE%20227/Lectures_Exam1/Ch4-Polymers.ppt. The show could be used as an introduction to polymers for your classes.

Is this Water Recycled Sewage?

Background Information (teacher information)

More on water purification

Water that is to become municipal drinking water is treated in a variety of ways to ensure that it is safe to drink. Depending on the source (a river vs. aquifer or artesian well water), it may be first screened, then treated with chlorine (which can kill or inactivate bacteria and viruses but not protozoan pathogens, such as *Giardia* and *Cryptosporium*) before being treated in a flocculation tank using the chemicals aluminum sulfate (alum), $Al_2(SO_4)_3$, and calcium hydroxide (slaked lime), $Ca(OH)_2$. These chemicals react to form aluminum hydroxide, $Al(OH)_3$, a sticky material that traps suspended particles which then precipitate. This is known as flocculation. The liquid is then passed through a sand filter to remove any unprecipitated flocculent. Sand filtration or other types of filters will also remove the pathogenic protozoa that are not killed by chlorination. Additional chlorination follows along with aeration (for taste enhancement), pH adjustment and fluoridation (1 ppm). The adjustment in pH is necessary because, if the water is acidic, it will react later with domestic water pipes, releasing, among others, undesirable Cu^{+2} and Cd^{+2} ions into a household's water pipeline. The water is now ready for public consumption.

Chlorination or chlorine addition to domestic water supplies takes place in one of three ways:

- Chlorine gas is bubbled into the water,
- A water solution of sodium hypochlorite, NaOCl is added,
- The solid, calcium hypochlorite, $Ca(OCl)_2$, is added to the water.

The chemistry of this particular treatment is the production of a weak acid, hypochlorous acid, HOCl. How this compound inactivates or kills bacteria and viruses is not clearly understood but it is thought to damage the selective permeability of the cellular wall which, in turn, is not able to control the entrance/exit of various chemicals that diffuse in and out of the organism's cellular interior (cytoplasm). Some waterborne viruses, such as enteric viruses and hepatitis A may be more tolerant to chlorine disinfection than some bacterial species, but it is not well understood how chlorine inactivates viruses. See http://www.sciam.com/article.cfm?id=how-does-chlorine-added-t.

An interesting aside is the fact that bacteria, along with some other organisms both microscopic and macroscopic (water hyacinths), are being studied for use in "cleaning" contaminated water of trace amounts of certain metals including zinc, selenium and even arsenic. Researchers are working with sulfate-reducing bacteria (SRB) that normally bind sulfate in oxygen-free water. Found in a flooded lead and zinc mining tunnel in Wisconsin, the species from the *Desulfobacteriaeceae* family of bacteria can survive in low oxygen environments and bind zinc with sulfate, forming spheres with zinc concentrations a million times higher than that found in the surrounding water. These bacteria have the potential to remove zinc, selenium, and even arsenic traces from various water sources. (http://www.sciam.com/article.cfm?articleID=000E6700-23DF-1C68-B882809EC588ED9F)

More on filtration

An interesting new “smart” material is being evaluated that both detects and helps to eliminate some organic water pollutants (chlorinated phenols found in preservatives, insecticides, and produced by paper mills, plastic and paint manufacturers). It is zinc oxide (ZnO). The important property of zinc oxide is its ability to emit visible light when it is exposed to ultraviolet light. When zinc oxide is exposed to the chlorinated phenols in water, its light emission decreases. This response is measurable for pollution concentrations as low as 1 ppm and takes less than a minute to occur. In addition, with the detection of the organic molecules, the ZnO can act as a catalyst in the breakdown of the molecules utilizing UV light. With conversion of the organics to harmless molecules, the ZnO again glows more brightly—indicating that the job is done. This material is considered to be a nanosensor.

Another design proposal for filtration utilizes recycled rubber tires which are ground up into crumbs (1-2 mm across). The system (now patented) is touted as being four times faster than standard filtration systems using sand, charcoal and stones of various diameters. The tire system uses tire crumbs of different sizes, starting with the largest crumbs at the top, with a gradient of smaller sizes progressing to the bottom (exit). If the system is used to filter wastewater, larger particles are trapped at the top and do not clog the system further down. A concern for this system using tires is the possibility that old tires may leach toxic chemicals, including heavy metals. Testing of the system and scaling up to full size is ongoing. See http://www.newscientist.com/article.ns?id=dn10637&print=true.

The history of water filtering can be found at http://www.historyofwaterfilters.com/.

More on portable personal water filters

In the developing world, clean and sanitized water is difficult to find. Water has always been the portal for disease-producing organisms, particularly diarrheal diseases. It is thought that one in five children die from diarrhea. This is more than die from AIDS, malaria and measles combined. For approximately 40% of the world’s population, there is no reliable safe drinking water. Attempts to improve this situation include the design and implementation of inexpensive pumps for underground water sources that can be both maintained and repaired for little cost and technical knowledge. These tend to be community pumps that are subjected to some abuse and contamination; e.g., livestock being brought into the vicinity of the pump where animal waste can get into the ground water, depending on the depth and type of well.

Attempts to develop individual household water filtration systems have met with varying degrees of success. Again, the goal is to provide a device that is affordable, that can be maintained simply (technical knowledge) and economically, and that has a long life span. One such recent development is a personal or household water filtration device called a “***Life Straw”.*** Of all the different methods for improving water quality and preventing diarrhea, filtration has the highest percent reduction in life-threatening diarrhea. The Life Straw can filter up to 18,000 liters of water, enough water to supply a family of five up to three years, before replacing the filtering mechanism. It works on gravity and does not need any electrical power. It uses an easy-to-clean pre-filter and a purification cartridge. The pre-filter is an 80 micron textile material that removes coarser turbidity-causing material and is cleanable. Before the water passes through a large delivery tube to the ultra-filtration membrane, it receives small doses of chlorine. The ultra-filtration membrane removes particles and microbes larger than 20 nanometers (bacteria, protozoan parasites, and viruses). The filtering system is routinely cleaned through back flow of water that has already been treated. A complete description of the system with photos as well as diagrams of usage can be found at www.lifestraw.com where there is a pdf file in English with all the details.

Nanotechnology is also coming into the picture with several new concepts, as reported in *Scientific American* (Moyer, M. W. A Killer Water Filter. *Scientific American,* **2010**, *303* (6), p 48). In order to be able to make the device available to those who can least afford expensive water treatment procedures, inexpensive materials such as cotton or tea bags are combined with nanotechnology for a cost of less than a penny. One idea avoids the problem of clogging of ultra-fine filters by bacteria. Cheap woven cotton is dipped into a mix of electrically conducting carbon nanotubes and silver nanowire. The silver acts as a bactericide (silver ions damage the genetic material of the bacteria. Low current electricity to kill the bacteria (breaks their cell membranes) is provided by two nine-volt batteries. The larger pores of the filter increase filtering time by 80,000 times compared with filters which trap microbes.

A second device is a tea bag filled with carbon granules coated with mircrobicide. The granules are encapsulated within nanofibers which trap the bacteria. The filter fits into the neck of an ordinary bottle, is capable of filtering one liter of polluted water, and costs about one cent each.

More on (EPA) standards for discharge of treated wastewater

On a worldwide scale, untreated sewage is an important agriculture commodity. It is estimated that a tenth of the world's irrigated crops use raw and untreated sewage gushing from sewer pipes into fields of food crops. This raises concerns about its affect on the health of people who ingest food crops treated with sewage. Various pathogens that are not killed can infect an individual who consumes the food, if it is not cooked. Another issue concerns heavy metals that become incorporated into the crops through ground water contamination by the sewage. In some countries sewage has a monetary value, just as does commercial fertilizer, a commodity that is sold to farmers. In the USA, there are strict government controls on the quality and use of treated sewage, also known as biosolids. Because of the waste treatment process here, there is no problem with pathogens in the discharge. On the other hand, there is a need to prevent heavy metals and certain organics, including pharmaceuticals (antibiotics, hormones), from becoming incorporated in wastewater sludge that is used as fertilizer. The sludge can be used for non-food crops and in areas where any percolation of the sludge's constituents will not become part of a public water supply such as public parts and some forest lands. New York City palletizes about 60% of its sewage sludge, which is then used as fertilizer on the citrus groves of Florida. Otherwise, the sludge is placed in special landfills that have a liner to prevent leaching and a network of pipes that can be used to collect the methane gas that is generated by anaerobic decay. Some municipalities actually have separate sewage collection/treatment facilities for industrial and domestic waste, to reduce the amount of heavy metals in the resulting sludge from domestic sources. (http://www.wisegeek.com/what-is-sewage-sludge.htm)

A list of just some of the hazardous chemicals and pathogens found in sludge can be found in the article "Sludge Contaminants" (http://www.sourcewatch.org/index.php?title=Sludge_contaminants).

> Sludge contaminants include dioxans, flame retardants, metals, organochlorine pesticides, 1,2-dibromo-3-chloropropane (DBCP), naphthalene, triclosan, nonylphenols, phthalates, nanosilver, and thousands more substances.

Sludge is defined as a "viscous, semisolid mixture of bacteria- and virus-laden organic matter, toxic metals, synthetic organic chemicals, and settled solids removed from domestic and industrial waste water at a sewage treatment plant." Over 60,000 toxic substances and chemical compounds can be found in sewage sludge, and scientists are developing 700 to 1,000 new chemicals per year. Stephen Lester of the Citizens Clearinghouse for Hazardous Wastes has compiled information from researchers at Cornell University and the American Society of Civil Engineers showing that sludge typically contains the following toxins:

- Polychlorinated biphenyls (PCBs) ;
- Chlorinated pesticides--DDT, dieldrin, aldrin, endrin, chlordane, heptachlor, lindane, mirex, kepone, 2,4,5-T, 2,4-D;
- Chlorinated compounds such as dioxins;
- Polynuclear aromatic hydrocarbons;
- Heavy metals--arsenic, cadmium, chromium, lead, mercury;
- Bacteria, viruses, protozoa, parasitic worms, fungi;
- Miscellaneous--asbestos, petroleum products, industrial solvents.

In addition, a 1994 investigation by the US General Accounting Office found that "the full extent of the radioactive contamination of sewage sludge, ash and related by-products nationwide is unknown." Most of the radioactive material is flushed down the drain by hospitals, businesses and decontamination laundries, a practice which has contaminated at least nine sewage treatment plants in the past decade.

In 1977, EPA Administrator Douglas Costle estimated that by 1990 treatment plants would be generating 10 million tons of sludge per year, a thought that "gives us all a massive environmental headache." In 1995 there were about 15,000 publicly-owned wastewater treatment works in the United States, discharging approximately 26 billion gallons per day of treated wastewater into lakes, streams and waterways. Before treatment, this wastewater contains over a million pounds of hazardous components. Sewage plants use heat, chemicals and bacterial treatments to detoxify 42 percent of these components through biodegradation. Another 25 percent escapes into the atmosphere, and 19 percent is discharged into lakes and streams. The remaining 14 percent--approximately 28 million pounds per year--winds up in sewage sludge.

Once created, this sludge must be disposed of somehow. Available methods include: incineration (which pollutes the air), dumping into landfills (which is expensive, and often leaches contaminants into groundwater), and ocean dumping (where it has created vast underwater dead seas). A fourth method --gasification, using sludge to generate methanol or energy--is described by EPA's Hugh Kaufman as the "most environmentally sound approach, but also the most expensive." A fifth approach --using sludge as plant fertilizer--was considered hazardous to health and the environment until the 1970s, but it has the advantage of being inexpensive. As budget concerns mounted in the late 1970s, the EPA began to pressure sewage plants to adopt the cheapest method available--spreading sludge on farm fields."

(Ref. http://www.sourcewatch.org/index.php?title=Sewage_sludge; considerable references in this website)

EPA recommendations for the use of sewage sludge are as follows:

1. Farmers should not accept sludge or apply it to land without a complete waste analysis.
2. The soil pH on sludge application sites should be maintained above 6.5 to lower plant uptake of heavy metals.
3. Sludge should be applied by directly injecting it in the soil or incorporating it into the soil within 24 hours to reduce the potential for odor and loss of nutrients in runoff.
4. For surface application, use only sludge that has been properly digested and stabilized at the treatment plant.
5. Do not apply sludge long before it will be utilized by the crop.
6. Keep accurate records of sludge applications. Sewage sludge containing heavy metals should be monitored to prevent contamination of soil or groundwater.
7. Excessive rates can contribute to leaching, erosion, and runoff losses; therefore, do not apply more than is needed.

(http://www.aces.edu/crd/publications/ANR-721.html)

Comment from Judith Nordgren, Managing Director, American Chemistry Council, Chlorine Chemistry Division:

February 9, 2011

The recent article “Is this Water Recycled Sewage?” by Gail Kay Haines provides a good overview of wastewater treatment, but could have benefited from a fuller description of chlorine disinfection.

The first job of any disinfectant is to make water biologically safe, preventing disease transmission. Water disinfectants, whether chlorine, ozone or UV light, are powerful oxidizers that are added to water to destroy harmful germs. In the process, disinfection byproducts form by interaction with stray organic matter, such as vegetable debris found in wastewater. By-products result from the use of any strong oxidant with material in the water. For example, ozone reacts with bromide to form bromate, a suspected carcinogen. By limiting the organic content of wastewater, it is possible to limit disinfection byproduct levels.

According to the Water Environment Federation, “…chlorine still maintains a prominent position as a useful wastewater disinfectant because the industry has learned more about effective and proper dosage levels, control of chlorine feed, desired residual levels and the importance of dechlorination.”

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Solutions**—Water is known as a solvent that dissolves many different categories of solutes in all three states of matter- solids, liquids, and gases forming solutions that are described in terms of density and composition of the homogeneous mixture (ions, molecules).

2. **Solubility**—Chemicals dissolved in the wastewater will not physically settle out (as in a mixture known as a suspension). Their solubility can be described in terms of the maximum mass of solute that can be dissolved per volume of solute at a given temperature. Analysis of discharged water would be analyzed for concentration of various metals, dissolved oxygen, and certain ions particularly phosphate, nitrate, and sulfate among others. Most dissolved chemicals will not be at their maximum concentration (saturation point) except possibly dissolved oxygen.
3. **Solvent**—In a homogeneous mixture, the component present in greatest amount (usually water) is the solvent in which other chemicals, solutes, are uniformly distributed (dissolved). This might be a good time to discuss water as the "universal solvent".
4. **Solute**—Chemicals that are dissolved in a solution. All the dissolved materials in wastewater can be considered solutes.
5. **Colloid**—One of the characteristics of the sewage mix is due to the particular size range of the particles that normally do not settle out, creating a cloudy appearance which can be diagnosed using a laser or strong beam of white light (search "the Tyndall effect"). These suspended particles can be removed through the chemical digestion of bacteria as well as filtration.
6. **Polar/Non-Polar**—What substances will dissolve in sewage water depends on their physical/chemical properties including polar/nonpolar properties. With the rule that "like dissolves like", only polar and ionic substances will dissolve in polar water. If molecular size is too large, the substances may precipitate out, contributing to the suspension characteristics of sewage and part of its preliminary treatment ("settling").
7. **Ions**—Solute particles with a charge, their small size limits how they might be removed from a solution such as filtered effluent. Reverse osmosis can be used if necessary.
8. **Acid/Base**—The pH of effluent that is released into the environment after treatment must be controlled close to neutrality, although that varies with anticipated use (see "More on water treatment" and "EPA recommendations for sludge treatment", above).
9. **Heavy Metals**—Depending on the source of the sewage (industrial vs. household), the effluent may contain heavy metals that must not become part of water used for irrigation of food crops as these metals can become concentrated in soil and food crops growing in that irrigated soil. Heavy metals have atomic masses greater than metals that are considered essential to human biochemistry; these heavy metals can interfere with important biological processes because they can bind to and interfere with enzymes that regulate these important biological processes. Normally, enzymes contain magnesium ions (Mg^{+2}) or calcium ions (Ca^{+2}) in their structure. Heavy metal ions can displace the magnesium and calcium ions causing the enzyme structure to become inoperable. Heavy metals include such elements as mercury (Hg), lead (Pb), cadmium (Cd), and antimony (Sb).
10. **Oxidation/Reduction**—An important process in waste-treatment, bacteria chemically digest nitrogen compounds in sewage reducing nitrogen of nitrates ($NO_3{}^{-1}$) to gaseous nitrogen molecules (N_2) that can become part of the important nitrogen cycle in the atmosphere. Other bacteria oxidize ammonia (NH_3) to nitrates ($NO_3{}^{1-}$) which is a form of nitrogen useful to plants, should the effluent be used for plant irrigation.
11. **Organic compounds**—Breakdown and excretion of biological organic compounds found in sewage is the substrate for bacterial action which reduces many of these substances into carbon dioxide, methane (anaerobic "decay"), water, nitrogen compounds, particularly the ions nitrite and nitrate, as well as ammonia from the amine groups.
12. **Trihalomethanes (THMs)**—These compounds are formed from organic molecules in sewage that react with various halogens, particularly chlorine, if present in the water effluent, forming a halogenated molecule, $CHCl_3$. It is thought that these THMs can trigger cancer formation if one is sufficiently exposed to them. Chlorine concentration in treated water is limited to 10 ppb.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"Water for drinking is pure water."** *Sometimes the term pure is used to refer to water that is free of disease-causing organisms, including bacteria, protozoan and viruses, rather than in the chemical sense by which water contains only one chemical, water!*
2. **"Filtering as we do in chemistry class can remove all dissolved substances in a water-based solution to produce pure water."** *If you evaporate the water from a filtered solution (the filtrate), you will see that there are various chemicals left behind that are visible to the eye. Obviously various solutes that were dissolved (and invisible to the eye) were small enough to pass through the filtering medium. Removing dissolved substances in water can be done through chemical reactions that produce a precipitate that is large enough to be stopped by the filter medium. Or water can be evaporated (as mentioned before), and re-condensed, leaving the dissolved solutes behind.*

Anticipating Student Questions (answers to questions students might ask in class)

1. **"If water is recycled, how is it possible for me to be drinking water that previously was part of some animal in East Africa? My local water treatment plant is not connected to East Africa!"** *Water moves around the world through the water cycle. Water evaporated from a source in one part of the world can become part of a cloud system that can move to another location in the atmosphere—multiple changes from cloud to rain (precipitation) back to cloud can eventually move that East African water to the USA with one more transformation from cloud to rain to flowing water to a water reservoir above or below ground and transfer to a water treatment plant, then to a home's water faucet. One person's excretion is eventually another person's drink of water!*
2. **"What is meant by 'pure' or purified water?"** *Pure water in chemical terms means water that contains only one chemical—that would be the water molecule. Pure water in that sense is hard to come by. After producing distilled water for the lab through boiling and condensation of the water vapor, carbon dioxide in the air dissolves in the water, producing a solution—no longer pure water. Sometimes, the term "pure" is used to designate water that has been treated to inactivate potentially harmful bacteria and viruses. But they remain part of the water as do other dissolved chemicals that originated in the soil and rock through which the water may have passed. Pure water is often associated with and implies "clean" rather than free of all chemicals other than water. The actual term for drinkable water is* ***potable*** *water.*
3. **"What causes acid rain?"** *Various gases in the atmosphere, many produced through the burning of fossil fuels, dissolve in the moisture of the atmosphere forming acidic "solutions" in the moisture droplets that can eventually coalesce to form rain droplets. Several of the more common acids include carbonic acid,* H_2CO_3*, formed when carbon dioxide gas dissolves in water; nitrous and nitric acids (*HNO_2 *&* HNO_3 *), which form from nitrogen dioxide(*NO_2*); sulfurous and sulfuric acids (*H_2SO_3 *&* H_2SO_4*), which form from sulfur dioxide,* SO_2 *.*

In-class Activities (lesson ideas, including labs & demonstrations)

1. The high school chemistry textbook titled “Chemistry in the Community” (ChemCom) has an engaging lab activity that simulates treating contaminated water (“foul water”) to demonstrate settling, filtering (primary, secondary) and the use of charcoal for removal of various molecules that produce odors.
2. You could have students further purify by distillation of the final product from the “foul water” in the first activity. First have students test the water for a variety of ions that have not been removed. If you are doing the ChemCom foul water lab, the remaining ions are Na^+ and Cl^-. If you want, you can also test for other ions in the water. The cheapest water testing kits are those sold for testing fish aquaria water (chloride, calcium, magnesium, iron, phosphate, and sulfate among others common to tap water). Repeat the chemical analysis on the product of water distillation to see what has been removed. You could also have students test the various water samples for conductivity (due to ions) before and after distillation. Students could make their own conductivity meter using well publicized schematics and inexpensive materials (pencils as electrodes). For a complete lab activity on testing various solutions and liquids as well as complete instructions for building a conductivity meter, see http://dwb4.unl.edu/chemistry/smallscale/SS035.html. An additional reference on the building of a conductivity meter is found at the ACS site (need membership to access)—http://pubs.acs.org/doi/abs/10.1021/ed074p570 . If you want to purchase the device, Flinn offers a kit for assembly at http://www.flinnsci.com/store/Scripts/prodView.asp?idproduct=21962&noList=1.
3. Distinguish between solution, suspension, and colloid; demonstrate flocculation as practiced in waste water treatment to precipitate suspended particles through the reaction using alum, $Al_2\,(SO_4)$ and slaked lime or calcium hydroxide, $Ca(OH)_2$. This reaction produces aluminum hydroxide, $Al(OH_3)$ which is a sticky, jelly-like substance that traps suspended particles, forming larger aggregates of material that settle out. The reaction is as follows:

   $$Al_2(SO_4)_3\text{ (aq)} + 3\,Ca(OH)_2\text{ (aq)} \rightarrow 2\,Al(OH)_3\text{ (s)} + 3\,CaSO_4\text{ (aq)}$$

   You could show this reaction in clear water with the formation of the white gelatinous precipitate of aluminum hydroxide.
   You could also prepare some “dirty” water by adding some clay soil to water, stirring, and pouring off the water suspension into a second container—leaving the excess undissolved soil in the first container. Then add the aluminum sulfate and calcium hydroxide to the suspension in the second container to see how much clearing of the water is accomplished by the reaction and formation of the gelatinous precipitate of aluminum hydroxide.
   You could also try to see the effect of various sized soil particles in suspension on the precipitate reaction’s ability to flocculate the suspended matter.
   For every 100 ml sample of water or solution, add a maximum of 3 grams aluminum sulfate to 2 grams of calcium hydroxide. Stir first to dissolve the chemicals. (Some of the calcium hydroxide may be insoluble.)
4. The nitrogen cycle is very important to the recycling and transforming of nitrogen to a variety of nitrogen-based compounds and ions. Special bacteria found in root nodules of legume plants convert atmospheric nitrogen gas (N_2) into nitrates and nitrites that are the usable forms of nitrogen for plants (eventually incorporated into protein molecules as the amine group). Redox is operating here, changing atmospheric nitrogen (N_2) into the nitrite and nitrate ions, converting nitrates into the amine group ($-NH_2$) of plant protein,

then later conversion of the amine group into ammonia, NH_3, (decay process) and back to molecular nitrogen (N_2) in the atmosphere.

5. Referring again to the Chemistry in the Community program, there are additional activities related to water in the sense of solution chemistry. They include:
   - water testing for common ions found in water such as iron, calcium, sulfate, and the chloride ion,
   - determining the solubility of a chemical substance with water as the solvent,
   - determining solubility limits of ions and polar/non-polar substances using a particular solvent, and
   - water softening using ion exchange resins.
6. Reverse osmosis devices are readily available for purchase from outdoor equipment stores. Discuss the science behind the operation of such a device. Compare with the process of osmosis and the use of a selectively permeable membrane. If they've had biology, remind students of the concept of concentration gradients and the passive movement of solutes and water across a membrane. You can also demonstrate the idea of osmotic pressure using a thistle tube with a dialysis membrane covering the top part of the tube. The top part is filled with a concentrated solution of NaCl or sugar, then invert in a beaker of distilled water. Over time, the osmotic movement of water into the thistle tube will cause a rise of fluid in the stem of the tube until an equilibrium is reached.

Out-of-class Activities and Projects (student research, class projects)

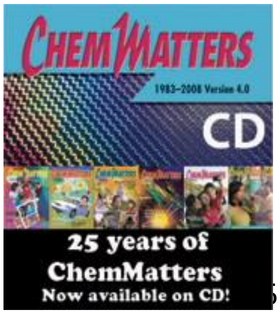
1. Investigate the state of affairs for the disposal of sludge from sewage treatment plants. Is the role of the government helpful? (See references under "Websites for Additional Information " that follow this section.)
2. Have students investigate the sewage disposal system in their town and where the treated sewage water is discharged. Students can also find the test results for the quality of the sewage water that is discharged. Does their treatment system use chlorine? UV light? Ozone? Does the EPA require their town's waste treatment plant to do tertiary treatment because of a high level of organics (and heavy metals?) in the sewage?

References (non-Web-based information sources)

Chemistry in the Community, (ChemCom), 4th Edition, W.H. Freeman & Co., NY, ISBN 0-7167-3890-2, Unit 1, "Water: Exploring Solutions".

Chemistry in Context, Wm. C. Brown, Publishers, Dubuque IA; ISBN 0-697-21948-8 Chapter 5, *"The Wonder of Water";* Chapter 7, "*Onondaga Lake: A Case Study"*

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for $30 (or a site/school license is available for $105) at this site: http://www.acs.org/chemmatters. (At the bottom of the Website screen, click on the *ChemMatters* CD image like the one at the right.)



Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Garber, C. Wastewater. *ChemMatters,* April, **1992**, *10* (2), pp 12-15. This article written by a chemist who works at a waste treatment plant is more detailed about the chemistry and biology of waste water treatment than the present (Feb.2011) CM article including pH and specific bacterial action.

Tinnesand, M. The Not So Simple Life of Filters, *ChemMatters*, February, **2008**, *26* (1), pp 14-15. This article details, with drawings, the workings of different kinds of filters, including those using nano materials as well as the process of reverse osmosis.

Brownlee, C. The Quest for a Clean Drink, *ChemMatters*, April, **2008**, *26* (2), pp 4-6. This article deals with a very specific situation for producing clean water from a source that is contaminated with toxic arsenic. Because this situation is in several developing countries such as India and Bangladesh, the design of the filter is to provide a low cost device. There is interesting chemistry utilized including the use of catalysts and polymer-based filtering systems.

Websites for Additional Information (Web-based information sources)

More sites on use of sewage as fertilizer

Water other than for drinking is needed in agriculture. A worldview shows the common use of sewage water for crops and the potential health problems. See http://www.newscientist.com/article.ns?id=dn6297.

http://cwmi.css.cornell.edu/sewagesludge.htm#sciencereview is an academic website (Cornell University) with a very extensive reference section for external (original) documents from government and other research facilities.

"Land Application of Sewage Sludges (aka Biosolids): The Case for Caution" (http://cwmi.css.cornell.edu/Sludge/NRC.pdf) is a 29-slide Power Point presentation to the NRC, 2001. (useful for a student presentation)

More sites on sewage treatment plant setup

http://ga.water.usgs.gov/edu/wwvisit.html is a website from the US Geological Service which succinctly describes the different stages of waste treatment related to a drawing of the physical setup at a sewage treatment plant with more detail than in the article.

A second diagrammatical presentation of an actual sewage treatment plant on Deer Island, MA with even more details than the previous reference is found at http://www.mwra.state.ma.us/03sewer/html/sewhow.htm; and a related site for the same treatment plant is http://www.mwra.state.ma.us/03sewer/html/sewditp.htm.

More sites on the hazards of wastewater sludge

http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm is the official EPA Guide to biosolids rules.

http://www.ejnet.org/sludge/#agriculture has much reference material on the concerns for contaminants in sludge that is being used in agriculture and generally getting into the environment where contaminants can get into water systems and the food chain.)

http://archive.centerforfoodsafety.org/sewage_slu.cfm is the site for a watchdog group that writes about the concerns for using sludge in agricultural situations.

A list of just some of the hazardous chemicals and pathogens found in sludge can be found in the article, “Sludge contaminants”, at http://www.sourcewatch.org/index.php?title=Sludge_contaminants. Sludge contaminants include dioxins and furans, flame retardants, metals, organochlorine pesticides, 1,2-dibromo-3-chloropropane (DBCP), naphthalene, triclosan, nonylphenols, phthalates, nanosilver, and thousands more substances.

Drugs Down the Drain: The Drugs You Swallow, the Water You Drink

Background Information (teacher information)

More on drinking water regulations

The main federally-passed regulation of drinking water is the Safe Drinking Water Act (SDWA). A brief summary is presented on the Environmental Protection Agency (EPA) website:

> Under SDWA, EPA sets standards for drinking water quality and oversees the states, localities, and water suppliers who implement those standards.
>
> SDWA was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells.
>
> SDWA authorizes the United States Environmental Protection Agency (US EPA) to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water. US EPA, states, and water systems then work together to make sure that these standards are met. (http://water.epa.gov/lawsregs/rulesregs/sdwa/index.cfm)

The EPA has established two levels of contaminants: Maximum Contaminant Level Goals (MCLGs) and Maximum Contaminant Levels (MCLs). *Chemistry in Context* describes the differences between these two levels:

> For each contaminant, the EPA has established a health goal, or Maximum Contaminant Level Goal (MCLG). This is the level, expressed in ppm or ppb, at which a person weighing 70 kg (154 lb) could drink two liters (about two quarts) of water containing the contaminant every day for 70 years without suffering any ill effects. Each MCLG includes built-in safety factors for uncertainties in standardizing data and for individual differences in sensitivity to the contaminant. An MCLG is not a legal limit with which water systems must comply; it is based solely on considerations of human health. For known cancer-causing substances (carcinogens), the EPA has set the health goal at zero, under the assumption that *any* exposure to the substance could present a cancer risk.
>
> It is important to recognize that the mere presence of a contaminant does not necessarily mean a serious health problem. For a problem to exist, the concentration of the contaminant must exceed the legal limit, expressed in ppm or ppb, referred to as a Maximum Contaminant Level (MCL). The EPA sets legal limits for each contaminant as close to the MCLG as possible, keeping in mind the practical realities of technical and financial barriers that may make it difficult to achieve the goals. Except for contaminants regulated as carcinogens, for which the MCLG

> is zero, most legal limits and health goals are the same. Even when they are less strict than the MCLGs, the MCLs provide substantial public health protection. (p206)

A list of contaminants along with their MCLGs and MCLs is available on the EPA website at http://water.epa.gov/drink/contaminants/index.cfm. They are collected in six major categories: microorganisms, disinfectants, disinfection byproducts, inorganic chemicals, organic chemicals, and radionuclides. As one example to contrast potential differences between MCLG and MCL as described above, benzene is listed in the organic chemicals category, with an MCLG of zero and an MCL of 0.005 mg/L. Thus, although the goal is zero, the legal limit is not. Information is also shared about potential health effects from long-term exposure above the MCL (for benzene: anemia; decrease in blood platelets; increased risk of cancer) and sources of the contaminant in drinking water (for benzene: discharge from factories; leaching from gas storage tanks and landfills). The list and levels continue to evolve as methods for detection and quantification of chemicals in water improves, and more information becomes available regarding contaminants and their potential health effects.

More on concentration and contaminants

The beginning of Washam's article uses the phrases "minute doses", "trace quantities of drugs", and "small traces"; these phrases qualitatively describe the concentration of pharmaceuticals in drinking water. The article also mentions terms for quantitative measurements of contaminants: parts-per-million (ppm), parts-per-billion (ppb), parts-per-trillion (ppt), and even parts-per-quadrillion (ppq). Students may be unfamiliar with these terms and the corresponding magnitude of each. However, the terms can be connected to a very familiar term, percentage (%), in that students can see that a percentage represents the idea "parts-per-hundred". The concentration of contaminants in drinking water could potentially be measured in percentages. However, these concentrations would often be much less than one percent. The additional ppm, ppb, ppt, and ppq expressions can all be useful, depending on how small the concentration of the substance of interest is. *Chemistry in Context* states some examples: "Drinking water often contains various substances naturally present at concentrations in the ppm range… Certain toxic water pollutants may also be present in the ppm concentration range. For example, the acceptable limit for nitrate (often found in well water in agricultural areas) is 10 ppm and the limit for fluoride is 4 ppm. Because some pollutants are of concern at concentrations much lower than even parts per million, they may be reported as parts per billion (ppb). For example, the acceptable limit for mercury in drinking water is 2 ppb" (p 191).

Chemistry in Context (p190) gives an example of parts per million: a 1 ppm solution of calcium in water contains 1 gram of calcium in 1 million (1,000,000) grams of water, then discusses that it is much more convenient to use liters than grams of water. It shows the equivalent: 1 ppm = (1 g solute / 1,000,000 g water) = (1 mg solute / 1000 g water) = (1 mg solute / 1 L water), if a liter is the volume occupied by 1000 g of water at 4 °C. Thus, 1 ppm can also be expressed as 1 mg of that substance per liter of water. With similar calculations, 1 ppb means 1 microgram (μg) per liter of water, 1 ppt = 1 nanogram per liter of water, and 1 ppq = 1 picogram per liter of water. Getting a feel for just how small a portion of a whole that these terms represent can be made easier using analogies. The website http://www.waterontheweb.org/resources/conversiontables.html presents many such analogies. Several are below; students could also formulate their own analogies or look up additional ideas online.

One part-per-million corresponds to:
  one inch in 16 miles
  one minute in two years
  one cent in $10,000

One part-per-billion corresponds to:
  one kernel of corn in a 45-foot high, 16-foot diameter silo
  one sheet in a roll of toilet paper stretching from New York to London

One part-per-trillion corresponds to:
  one square foot of floor tile on a kitchen floor the size of Indiana
  one drop of detergent in enough dishwater to fill a string of railroad tank cars ten miles long

One part-per-quadrillion corresponds to:
  one postage stamp on a letter the size of California and Oregon
  one human hair out of all the hair on all the heads of all the people in the world

More on water testing

Depending on the contaminant being studied, analytical methods for detection and quantitative analysis of its concentration vary widely. They can include methods from colorimetric testing to high-tech instrumentation such as inductively coupled plasma—atomic emission spectrometry (ICP–AES) and many others. The EPA website "Drinking Water Analytical Methods" ([http://water.epa.gov/scitech/drinkingwater/labcert/analyticalmethods.cfm - approved](http://water.epa.gov/scitech/drinkingwater/labcert/analyticalmethods.cfm#approved)) states "Water systems must use EPA-approved analytical methods when analyzing samples to meet federal monitoring requirements or to demonstrate compliance with drinking water regulations. … Approved methods are developed by EPA, other government agencies, universities, consensus methods organizations, water laboratories, and instrument manufacturers." The website contains multiple downloadable pdf files containing extensive lists of all methods currently approved for the analysis of drinking water.

As one example of a method that can detect certain contaminants in the ppb range, *Chemistry in Context* states "Gas chromatography is the normal analytical method for trace amounts of a wide variety of toxic substances in drinking water. These include pesticides, PCBs, dioxins, industrial solvents, and gasoline or other petroleum products" (p 218). It goes on to describe gas chromatography (GC):

> In GC, molecular solutes in water are first extracted from a large sample of water into a small volume of a non-ionic liquid such as octane. This extraction concentrates the solutes to be analyzed. A very small portion of the extract is injected into a flowing gas stream that passes down a long, heated tube coated with an absorbing material; a detector is at the far end. Components in the sample move down the tube at various rates, thus reaching the detector at different times. The signal from the detector is displayed on a recorder; each peak corresponds to a different substance. For each plotted peak, the time required for the substance to reach the detector identifies the substance, while peak area measures its concentration. (p218)

Testing methods to detect and analyze levels of pharmaceuticals and personal care products continue to be developed. A June 2010 report discussed the work of Underwriters

Laboratories (UL), who "has developed two new methods that provide cutting-edge and cost effective analytical services for contaminants such as Pharmaceutical and Personal Care Products (PPCPs) in the 160,000 water supplies in the U.S." The report lists many "contaminants of emerging concern" that the tests can detect and analyze, including acetaminophen, triclosan, fragrances, DEET, and more. (http://www.ul.com/global/eng/pages/corporate/newsroom/pressreleases/, click on the link for the June 21, 2010 report)

More on water treatment

As Washam's article states, water treatment plants treat ground and surface water to remove bacteria and other contaminants and produce potable water for public consumption. This can include removal of certain pharmaceuticals, depending on the processes used during the water treatment.

Water progresses through various stages in a water treatment plant. The particular stages and processes used may be different from plant to plant. For example, the article describes different disinfection processes that are available, such as chlorination and ozone treatment. Chlorination is widely used in the U.S.; a much smaller percentage of plants use ozone treatment, although it is becoming more widespread.

Typical stages in water treatment are listed in *Chemistry in the Community* as screening, pre-chlorination, flocculation, settling, sand filtration, post-chlorination, and optional further treatment (p88).

- Screening—As water is taken up from its source, it is passed through a screen to filter out larger objects, such as branches and human-generated litter.
- Pre-chlorination—Pre-chlorination is a potential next stage. It is useful in several stages of the treatment process, such as aiding in coagulation, controlling algae problems, and reducing odor problems; it increases safety in disinfecting heavily contaminated water due to its longer contact time (http://water.me.vccs.edu/concepts/chlorination.html). However, this longer contact time also allows an increased time for chlorine byproducts to form trihalomethanes in the water, which as carcinogenic substances.
- Flocculation and settling—During flocculation, aluminum sulfate ($Al_2(SO_4)_3$) and calcium hydroxide ($Ca(OH)_2$) are added. As stated in *Chemistry in Context* (p 208), these compounds react to form a sticky gel of aluminum hydroxide, which collects suspended clay and dirt particles on its surface.

  $$Al_2(SO_4)_3\ (aq) + 3\ Ca(OH)_2\ (aq) \rightarrow 2\ Al(OH)_3\ (s) + 3\ CaSO_4\ (aq)$$

  The $Al(OH)_3$ gel settles slowly carrying with it the suspended particles down into a settling tank.
- Filtration—Water may then pass through different stages of filtration, including gravel and/or sand.
- Post-chlorination—Disinfection is usually the last stage in water treatment; chlorination is the most commonly-used method of disinfection. The benefit to making it a post-chlorination stage is that by then, the water has had many substances already removed or reduced, which limits the potential of their interaction with chlorine to form undesirable compounds. There are several different methods used in chlorination, outlined in *Chemistry in the Community* (p 90).

    - Chlorine gas, Cl_2, is bubbled into the water. This substance is not very soluble in water. Chlorine does react with water, however, to produce a water-soluble, chlorine-containing compound.
    - A water solution of sodium hypochlorite, NaOCl, which is the active ingredient in household bleach, is added to the water.
    - Calcium hypochlorite, $Ca(OCl)_2$, is dissolved in the water. Available as both a powder and small pellets, calcium hypochlorite is often used in swimming pools. It is also a component of some solid household products sold as bleaching powder.

  All three methods generate hypochlorous acid, HOCl. The level of chlorination is adjusted so a low concentration of HOCl remains in the water. This protects against contamination after it leaves the water treatment plant. This can leave a taste and odor that the consumer can detect in tap water.

- Optional further treatment—One example of this is fluoridation of drinking water. Water around the U.S. has natural fluoride levels that range from 0.1 to more than 12 ppm. The optimal level of fluoride for preventing tooth decay is 0.7–1.2 ppm. Water treatment plants can adjust the fluoridation to optimal levels (http://esa21.kennesaw.edu/activities/drink-water-trt/drink-water-trt.pdf). Acidic water may be partially neutralized with calcium oxide (CaO) to avoid corrosion of pipes or leaching of heavy metals from the pipes. Sometimes water is sprayed into the air to remove volatile chemicals that create objectionable odors and taste. (*Chemistry in Context*, p209)

While chlorination is the most widely used method of disinfection, other methods are available. Each method has its own advantages and drawbacks. As mentioned earlier, chlorination leaves HOCl present in the water. HOCl can lead to formation of trihalomethanes (THMs). The meaning of the word can be discerned by breaking it down into parts: trihalomethanes are chemical compounds in which three (tri-) of the four hydrogen atoms in methane (-methane) are replaced by halogen atoms (-halo-). The one most commonly mentioned is chloroform ($CHCl_3$), which is suspected of causing liver cancer. Aside from negative health effects, THMs can also give drinking water an unpleasant taste. HOCl reacts with humic acids, which are formed through the breakdown of dead plant matter, to form THMs. There are several options that can help to eliminate THMs and their associated health risks. Treatment plants can remove as much humic acid as possible before chlorination steps. Activated charcoal filters can also be used to remove organic compounds, including THMs. As Washam's article states, these filters can be expensive and difficult to clean used filters of contamination. Pre-chlorination can be eliminated, relying on post-chlorination, which can still contribute to THMs formation, although at a lower level. A reduced level of chlorine can allow for more bacterial growth, however. Or, alternative disinfection processes can be used instead of chlorination.

Gaseous ozone (O_3) is another option for disinfection and is extensively described in the article. *Chemistry in Context* (p209) discusses its advantages and disadvantages. Advantages to its use include that a smaller concentration of it is needed, compared to chlorine, and that it is more effective than chlorine against water-borne viruses. Disadvantages include that is more expensive due to the cost of on-site ozone generating equipment and becomes economical only for large water treatment plants. It also decomposes quickly, so that it does not protect water after it leaves the treatment plant. Low doses of chlorine may be added to ozonated water as it leaves the treatment plant. Ozone can also react with bromide resulting in the formation of carcinogenic by-products, including bromate, bromoform, and dibromoacetic acid (http://www.epa.gov/nrmrl/wswrd/dw/smallsystems/bcr.html).

The use of ultraviolet radiation is another disinfection option. The history, science, and use of UV light to disinfect drinking water is explained in a 2006 Environmental Protection Agency document available at (http://www.epa.gov/ogwdw000/disinfection/lt2/pdfs/guide_lt2_uvguidance.pdf, see section 2). Information from that document includes the following: Disinfection involves generating UV light with the desired germicidal properties and transmitting the light to pathogens. UV disinfection primarily occurs due to the germicidal action of UV-B (280 to 315 nm) and UV-C (200 to 280 nm) light on microorganisms. Typically, UV light is generated by applying a voltage across a gas mixture, resulting in a discharge of photons. Nearly all UV lamps currently designed for water treatment use a gas mixture containing mercury vapor, because it emits light in the germicidal wavelength range. While chemical disinfectants inactivate microorganisms by destroying or damaging cellular structures, UV light inactivates them by damaging their nucleic acid, thereby preventing them from replicating. As of the year 2000, more than 400 UV disinfection facilities worldwide were treating drinking water. Since 2000, several large UV installations across the U.S. have been constructed or are currently under design. The largest of these facilities includes a facility in operation in Seattle, WA, and a facility under design for the New York City Department of Environmental Protection. Disinfection with UV radiation is very fast and produces no residual by-products. However, it can be expensive for large facilities and since it doesn't remain in the water, it cannot protect the water from contamination after it leaves the water treatment plant.

More on disposal of pharmaceuticals

As Washam's article states, the toilet has long been considered the best place for disposal of unused medications. However, now that researchers are more aware of the eventual fate and potential effects of these discarded medications, additional guidelines have been put in place for expired or unneeded medications.

For a limited number of medications, the recommended method of disposal is still to flush them down the sink or the toilet. The U.S. Food and Drug Administration describes the reasoning behind these special cases: "However, certain medicines may be especially harmful and, in some cases, fatal in a single dose if they are used by someone other than the person the medicine was prescribed for. … they could be especially harmful to a child, pet, or anyone else if taken accidentally. … flushing these medicines down the sink or toilet is currently the best way to immediately and permanently remove the risk of harm from the home" (http://www.fda.gov/Drugs/ResourcesForYou/Consumers/BuyingUsingMedicineSafely/EnsuringSafeUseofMedicine/SafeDisposalofMedicines/ucm186187.htm). A list of these medications at the same site includes Demerol, Oxycontin, and Percocet, as well as some medications delivered through a patch system. Typically, the medication label or patient information will alert users if it should be disposed of in this way.

The Food and Drug Administration also addresses the question "How big of a problem is accidental exposure to medicine in the United States?" (http://www.fda.gov/Drugs/ResourcesForYou/Consumers/BuyingUsingMedicineSafely/EnsuringSafeUseofMedicine/SafeDisposalofMedicines/ucm186188.htm). Their answer summarizes data from the 2007 Annual Report of the American Association of Poison Control Centers' national Poison Data System, stating: "In 2007, there were 255,732 cases of improper medicine use reported to Poison Control Centers in the United States. Approximately 9% of these cases

(23,783) involved accidental exposure to another person's medicine. Approximately 5 thousand of these accidental exposure cases involved children 6 years and younger." Many cases have involved medicine stored in child-resistant containers; one case even included ingestion of a discarded transdermal patch. Extensive reports are released every year; the 2008 report is available at http://www.aapcc.org/dnn/Portals/0/2008annualreport.pdf.

The United States Office of National Drug Control Policy has a one-page document online (http://www.whitehousedrugpolicy.gov/publications/pdf/prescrip_disposal.pdf) that gives tips for the proper disposal of prescription drugs. It states if the drugs are not labeled to be flushed, you may be able to take advantage of community drug take-back programs or other programs, such as household hazardous waste collection events, that collect drugs at a central location for proper disposal. It suggests calling your city or county government's household trash and recycling service to ask if such a program is available in your community. Mail-back programs have also been developed, where medications can be returned via special envelopes in the U.S. Mail. The Environmental Protection Agency awarded a grant to such a program in Maine; they report on its results and success at http://www.epa.gov/aging/RX-report-Exe-Sum/. Walgreens, a national drugstore chain, launched a similar disposal program in September 2010 (http://news.walgreens.com/article_display.cfm?article_id=5343). A special postage-paid envelope can be purchased for $2.99 at Walgreens pharmacies, to mail prescription or over-the-counter medications for disposal. The company states "…it will be sent to an approved medication incinerator. There, a licensed law enforcement official is onsite as part of a quality control system to ensure no envelope is tampered with or opened." They even say the resulting ashes can be used for making "green" building materials.

The 2011 article "Disposal practices for unused medications around the world", published in *Environment International* (see the full text at doi:10.1016/j.envint.2010.10.002) surveyed studies of disposal practices in different countries. They concluded "…patients still very much lack the knowledge as to the proper disposal of their unused medication and how improper disposal methods may affect the environment. Confusion exists in different countries as many countries lack adequate guidelines for the 'proper' disposal of unused medications." They point out that more education is needed, along with official guidelines relevant to each country.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Medicinal chemistry**—Medicinal chemistry focuses on the design and development of pharmaceuticals. A study of drug molecules and drug design could be coupled with a discussion of the increasing concern for the health effects of these compounds once they enter the water supply after excretion by the human body or after disposal.
2. **History**—Progress in the ability to measure smaller and smaller concentrations of contaminants in water and the development of disinfection and other water treatments can be traced through history. One can also research the cleanliness (or lack thereof) of drinking water throughout history, including its effects on the spread of sicknesses such as cholera.
3. **Instrumentation**—Methods of water testing and instrumentation used in testing could be discussed, including a comparison between tests that are qualitative, in that they only identify whether a substance is present or not, and those that are quantitative, in that they measure the amount of substance present. The sensitivity of testing can also be discussed.

For example, a particular test may not be able to sense a very small concentration of a substance, even though that substance may be present.

4. **Concentration—**Measuring the amount of a particular substance in water involves the use of concentration units that may be unfamiliar to students. For example, many contaminants found in water may be of such minute amounts that it is more convenient to express the concentrations using parts-per-million, parts-per-billion, and beyond. These units can be compared to the most commonly-learned chemistry concentration unit, molarity.
5. **Environmental chemistry—**The topics of maintaining a clean and safe water supply through environmentally-conscious actions and continued advances in water testing and analysis are closely tied with environmental chemistry.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"When you take a drug, your body uses all of the active ingredients."** *When you take a drug, your body uses only a portion of the active ingredients. The rest is excreted. You release some of the drug into the sewer system when you flush the toilet.*
2. **"All drugs present in wastewater are from pills and liquid pharmaceuticals taken orally."** *Medicated gels, creams, and lotions that we put on our skin are washed down the drain as we bathe. The antibacterial triclosan is also found in countless household products, including antibacterial soap, which can also enter the wastewater stream.*
3. **"The most widely-used prescription drugs are found in the highest concentrations in waterways."** *Some of the most widely-used prescription drugs did not turn up in testing of waterways. Instead, drugs that are seldom used were among the top contaminants. The reason lies in the chemistry of wastewater treatment. Treatment plants normally disinfect wastewater with chlorine; chlorine completely removes some drugs, while others escape chlorine treatment.*
4. **"One method of treatment is able to remove all pharmaceuticals from water."** *No single treatment is able to remove all pharmaceuticals from water, and some treatments have drawbacks. For example, chlorine only removes certain drugs and can react with pharmaceuticals to form more toxic compounds. Ozone removes 80% of all pharmaceuticals, but is expensive and has no residual effect. Pharmaceuticals in water can be minimized, but we will never remove every trace.*
5. **"Pure drinking water contains no additional substances."** *Water that we consider "pure" enough to drink always contains additional substances. Limits are placed on how much of certain substances are allowed to be present in U.S. drinking water. However, these limits are rarely set at zero. Attaining this level of purity is cost-prohibitive, and in the case of certain substances, potentially unnecessary. Some bottled water manufacturers actually add certain minerals to their water to enhance its taste.*
6. **"The best way to dispose of unused medication is by flushing it down the toilet."** *Flushed pharmaceuticals often reemerge in freshwater bodies. To minimize the environmental risk, guidelines now say that one should only flush or pour drugs down the drain if the accompanying patient instructions advise the user to. Other drugs should be removed from their containers, crushed, and mixed with an unappetizing substance, then sealed in a plastic bag, and thrown in the garbage.*

Anticipating Student Questions (answers to questions students might ask in class)

1. **“What can I do to help?”** *Being aware of the current concerns and guidelines regarding pharmaceuticals and personal care products is a good start. All of us can benefit from remembering that the pharmaceuticals and personal care products we purchase will potentially interact with our water supply, or will need to be properly disposed of if we don’t use all of the product. You could volunteer at a community take-back drug disposal event, or, if your community doesn’t offer one, investigate how such a program could be started.*
2. **“Where can I find information about my community’s water supply?”** *The EPA says that for community water systems, “Each year by July 1 you [your family] should receive in the mail a short report (consumer confidence report, or drinking water quality report) from your water supplier that tells where your water comes from and what’s in it” (http://water.epa.gov/lawsregs/rulesregs/sdwa/ccr/index.cfm). From that site, there are also links to see if your community’s report is posted on-line and frequent questions about the reports.*
3. **“Why do the disposal guidelines say to flush some drugs and not others?”** *Certain medicines may be especially harmful and, in some cases, fatal in a single dose if they are used by someone other than the person for which the medicine was prescribed. Flushing the medicines helps to immediately remove the drugs from the home.*
4. **“What happens to discarded pharmaceuticals after they are collected?”** *Typically, pharmaceuticals are taken to an approved facility for incineration.*

In-class Activities (lesson ideas, including labs & demonstrations)

1. To get a feel for how small the amounts of solute represented by parts-per-million, parts-per-billion, etc. are, and in connection with a discussion of detection limits, students can perform a serial dilution of Kool-Aid. One spoonful of presweetened Kool-Aid or other drink mix can be added to a cup of water. After mixing, one spoonful can be taken from that cup and mixed in a second cup with nine spoonfuls of water, and so on with several cups. Students can then taste the solutions, beginning with the most dilute, and observe at what point they begin to be able to taste the drink mix and at what point they see a noticeable color in the cup. *JCE* Classroom Activity #69 “A Cool Drink! An Introduction to Concentrations” presents this idea and is available to *J. Chem. Educ.* subscribers at http://pubs.acs.org/doi/abs/10.1021/ed082p240A. A similar activity is part of the teaching packet available at http://www.iisgcp.org/fishschool/FishSchoolLessonPlans.pdf*.* An activity showing a similar idea (but no tasting) is performed with food coloring in a well plate (http://teacherweb.com/CA/CastroValleyHighSchool/SilviaPerri/Concentration.doc).
2. Testing for cations and anions in solution can be performed, even on very dilute solutions that students may think appear too clear and colorless to contain any ions that typically show a color, such as copper(II) sulfate. In one experiment, students make a copper(II) sulfate solution, then serially dilute it until it is colorless. They then use ammonia, which indicates the presence of copper ions through formation of a blue copper-ammonia complex. The laboratory experiment “#14 Experimenting with Copper(II) Solutions” is available at http://www.terrificscience.org/lessonpdfs/Copper(II)Solutions.pdf. Other tests for anions and cations are listed at http://library.thinkquest.org/2923/tests.html. Experiments involving the identification of cations and anions in solution are also available online; for example, see http://ck042.k12.sd.us/Unit%209%20Docs/Qualintro.pdf.

3. Many water purification experiments are available, so students can recreate some of the processes their drinking water typically undergoes. The ACS publication, *Chemistry in the Community*'s laboratory experiment "Foul Water" is a widely-used experiment where students "use several water-purification procedures: oil–water separation, sand filtration, and charcoal adsorption and filtration" (pp10–15). Lab directions from the student textbook can be seen at Google Books (http://books.google.com) and searching for "Chemistry in the Community". Another example is "62. Purification of Water", (Borgford, C. L.; Summerlin, L. R. *Chemical Activities, Teacher Edition*, American Chemical Society, 1988, pp 179–181). In the experiment, students treat muddy water with lime, then alum. Another is *JCE* Classroom Activity #60 "Water Filtration" and is available to *J. Chem. Educ.* subscribers at http://pubs.acs.org/doi/abs/10.1021/ed081p224A. Students prepare a water filtration column using gravel, sand, and activated charcoal, and use it to filter water contaminated with rust, oil, vinegar, soil, and leaves. Similar experiments can be found online, such as http://portal.acs.org/portal/fileFetch/C/CSTA_015084/pdf/CSTA_015084.pdf, http://www.lvwash.org/html/resources_materials_exp_filtration.html and http://www.freedrinkingwater.com/water_quality/experiment1-purification-watercycle.htm.
4. Illustrate how small an amount of the Earth's water supply is available for drinking water. *Chemistry in the Community* describes a demonstration: "Model Earth's water supply with a 1-L beaker or graduated cylinder of water, pouring out various volumes into containers … For example: Start with an empty 1-L graduated cylinder, add 970 mL of water to indicate that 97% of all Earth's water comes from the oceans, add 21 mL for glaciers and ice caps, 6 mL for groundwater, 1 mL (or equivalent, roughly 20 drops) for lakes, a few drops for atmospheric moisture, and just a drop for rivers. Using water colored blue with food coloring makes for a visually appealing demonstration." Other variations are available online at http://www.play-with-water.ch/d4/index.cfm?pageNo=7&systemNo=4&eksperimentNo=402&language=en and http://www.whittsclass.com/Word/Water Distribution on Earth.doc.
5. Many laboratory manuals include water testing experiments. The *Chemistry in the Community* textbook includes an investigation that uses qualitative tests for calcium, iron(III), chloride, and sulfate ions (pp42–45). The *Chemistry in Context* laboratory manual has a series of experiments related to water: #12 Measurement of Water Hardness, #13 Measurement of Chloride in River Water, #14 Analysis of Bottled Water, and #15 Iron in Drinking Water (pp85–112). Many science suppliers also offer water testing kits and test strips. Instruments such as Vernier probes and sensors can also be used in water testing (see http://www.vernier.com/cmat/wqv.html).

Out-of-class Activities and Projects (student research, class projects)

1. Students could collect and analyze samples from a local body of water as a year-long project.
2. Classes could take a field trip to a wastewater treatment plant or municipal water treatment plant to learn about the processes water undergoes and the testing these plants are required to do.
3. Students could volunteer to help at a pharmaceutical-collection drive, if one is being held locally. Or, if there is no local event, students could investigate which agencies or organizations could be encouraged to hold such an event.
4. Hold a debate regarding the risks and benefits of chlorination of water supplies or the addition of fluoride to drinking water.

5. Students could spend several days keeping a diary of their water use and then analyze the amount of water used during that period. Charts for keeping track of water use are widely available online. A few examples are http://www.thirteen.org/h2o/print/p_educators_lesson4_h2.html, http://www.arps.org/users/hs/thompsom/chemcom/unit_1/Water_Use_Diary.pdf, and even a free iPhone/iPod Touch/iPad application at http://itunes.apple.com/us/app/my-water-diary/id333197878?mt=8.
6. Most water suppliers provide annual reports detailing the quality of the water they provide. Have students examine one of these reports. Using their current knowledge of science, do students find these reports understandable? Links to many cities' drinking water quality reports are available through http://www.epa.gov/ogwdw000/ccr/whereyoulive.html. One example is http://www.denverwater.org/docs/assets/9A0474D0-BCDF-1B42-DDA16D94EFB34AAA/2009_water_quality_report1.pdf.

References (non-Web-based information sources)

Stanitski, C. L.; Eubanks, L. P.; Middlecamp, C. H.; Stratton, W. J. *Chemistry in Context: Applying Chemistry to Society*, 3rd ed.; American Chemical Society: Washington, DC, 2000.

Stratton, W. J.; Silberman, R. G.; Stanitski, C. L.; Schwartz, A. T. *Laboratory Manual to Accompany Chemistry in Context: Applying Chemistry to Society*, 3rd ed.; American Chemical Society: Washington, DC, 2000.

Chemistry in the Community, 5th ed.; American Chemical Society: Washington, DC, 2006.

Borgford, C. L.; Summerlin, L. R. *Chemical Activities*, teacher ed., American Chemical Society, 1988, pp 179–181 describes an experiment for the purification of water that shows the effect of lime and alum on muddy water.

Jacobsen, E. K. *J. Chem. Educ.* **2004**, *81* (2), pp 224A–B describes an activity where students make a water filtration column and use it to filter water (full text available for subscribers at http://pubs.acs.org/doi/abs/10.1021/ed081p224A).

Fictorie, C. P. *J. Chem. Educ.* **2010**, *87* (2), pp 144–145 presents a book review of *The Occurrence and Fate of Pharmaceuticals and Personal Care Products in the Environment*. The review is freely available at http://pubs.acs.org/doi/full/10.1021/ed800069g. The book is fairly expensive, but could be a resource for teachers who wish to pursue a deeper study of the topic.

Websites for Additional Information (Web-based information sources)

More sites on pharmaceuticals and personal care products

The Environmental Protection Agency maintains a "Frequent Questions" page regarding topics on pharmaceuticals and personal care products (PPCPs), including such questions as "What are the major sources of PPCPs in the environment?", "What are the major issues with respect to effects?", and "How can I contact scientists working on this topic?" (http://www.epa.gov/ppcp/faq.html)

An archive of the web seminar "Pharmaceuticals and Personal Care Products in the Environment", presented by the Environmental Protection Agency, is available at http://www.clu-in.org/conf/tio/ppcp1_092606/.

"An AP Investigation: Pharmaceuticals Found in Drinking Water" collects multiple pieces from the Associated Press related to drugs in drinking water, along with a follow-up of the reaction of others to that information. (http://hosted.ap.org/specials/interactives/pharmawater_site/)

Information on the "Emerging Contaminants in the Environment" research project of the U.S. Geological Survey is available at http://toxics.usgs.gov/regional/emc/index.html. It includes recent information on published studies, development of analytical methods, ecological effects, and more.

The U.S. Geological Survey summarized results of a study that showed three hormones that can potentially biodegrade in stream and groundwater environments. (http://toxics.usgs.gov/highlights/hormones_degrade.html)

The U.S. Geological Survey summarized results of a 2004–2009 study that showed "pharmaceutical manufacturing facilities can be a significant source of pharmaceuticals to the environment." (http://toxics.usgs.gov/highlights/PMFs.html)

A special issue of the journal *Environmental Toxicology and Chemistry* focuses on pharmaceuticals and personal care products in the environment. The issue's table of contents is available at http://onlinelibrary.wiley.com/doi/10.1002/etc.v28:12/issuetoc; full texts of the articles are freely available through links on that page.

More sites on drinking water

The U.S. Geological Survey offers the webpage "Water Science for Schools", with information on topics such as water quality and water use, along with an activity center that contains challenge questions, opinion surveys, and questionnaires. (http://ga.water.usgs.gov/edu/)

The Environmental Protection Agency document "25 Years of the Safe Drinking Water Act: History and Trends" reports on the Safe Drinking Water Act, from prior to its start in 1974, to its amendments over the following 25 years, and future challenges. (http://permanent.access.gpo.gov/websites/epagov/www.epa.gov/safewater/sdwa/trends.html) A four-page fact sheet on the report is also available at http://www.epa.gov/safewater/consumer/pdf/hist.pdf.

The Environmental Protection Agency offers a "Ground Water & Drinking Water" web page that is a good jumping-off site for information on categories such as drinking water protection, water security, and standards & risk management. (http://water.epa.gov/drink/index.cfm)

Medline Plus offers the webpage “Drinking Water”, which is packed with links related to specific compounds in water, issues and organizations related to drinking water, children’s resources, and more. (http://www.nlm.nih.gov/medlineplus/drinkingwater.html)

The World Health Organization webpage “Water, Sanitation and Hygiene” offers links related to drinking-water quality, water supply and sanitation monitoring, wastewater use, and more. (http://www.who.int/water_sanitation_health/en/)

The U.S. Geological Survey’s national water-use information program compiles and shares data on the nation’s water usage. (http://water.usgs.gov/watuse/)

The National Drinking Water Clearinghouse “is a public service organization dedicated to helping small communities by collecting, developing, and providing timely information relevant to drinking water issues.” They share links to their publications, including an “Ask the Experts” section which contains thought-provoking questions and answers regarding water use and treatment.
(http://www.nesc.wvu.edu/drinkingwater.cfm)

Drinking water contaminant fact sheets are available for specific contaminants at http://www.freedrinkingwater.com/water-contamination/water-contaminants-pollutants-list.htm.

More sites on concentration and contaminants

The article “What does ppm or ppb mean?” appeared in *On Tap* magazine and is a good explanation of the two concentration terms, along with analogies for each.
(http://www.nesc.wvu.edu/ndwc/articles/ot/fa04/q&a.pdf)

A two-page fact sheet “How are Contaminant Concentrations Expressed?” succinctly describes ppm and ppb.
(http://www.dec.state.ak.us/spar/csp/guidance/cont_concentrations.pdf)

A hands-on activity designed for eighth graders, keyed to North Carolina standards, uses serial dilution of food coloring solutions to discuss ppm and ppb.
(http://www.uncsrp.org/resources/Serial_Dilution_Activity.pdf)

More sites on water testing

The original report mentioned in the Washam article on 1999–2000 U.S. Geological Survey testing of U.S. streams is available at http://toxics.usgs.gov/pubs/OFR-02-94/. The information was also published in the journal *Environmental Science & Technology*; the abstract is available at http://pubs.acs.org/doi/abs/10.1021/es011055j, but the full article can be accessed by subscribers only.

The Environmental Protection Agency describes a 2006 pilot study of pharmaceuticals and personal care products in fish tissue at http://water.epa.gov/scitech/swguidance/ppcp/fish-tissue.cfm, along with an extension of the study at http://water.epa.gov/scitech/swguidance/ppcp/fish-expand.cfm. A 2009 *Environmental*

Toxicology and Chemistry article appears to report on the 2006 results at http://onlinelibrary.wiley.com/doi/10.1897/08-561.1/full.

A typical day of water testing is described at the web page "Getting Your Feet Wet—A Day in the Life of a USGS Water Scientist". (http://www.usgs.gov/homepage/science_features/water_scientist.asp)

U.S. Geological Survey scientists report on a new laboratory method they developed "to measure trace levels of 22 human-health pharmaceuticals in surface and ground water. … The new method uses an analytical procedure that combines solid-phase extraction with high-performance liquid chromatography–electrospray ionization mass spectrometry (HPLC–ESI–MS)." (http://toxics.usgs.gov/highlights/pharmaceuticals_method.html)

World Water Monitoring Day is "an international education and outreach program that builds public awareness and involvement in protecting water resources around the world by engaging citizens to conduct basic monitoring of their local water bodies." (http://www.worldwatermonitoringday.org/index.html)

The web site "Testing for Ions" is an interactive tutorial that illustrates testing for a variety of ions, which is described as an example of what an environmental scientist might do, when analyzing water for pollutants. (http://www.absorblearning.com/chemistry/demo/units/LR1106.html - Testingfornegativelychargedions)

More sites on water treatment

The article "Pioneering Science for Safe Water: Harriette Chick Reveals the Laws of Disinfection" focuses on the role Dr. Chick's research played in making drinking water safe. (http://www.americanchemistry.com/s_chlorine/science_sec.asp?CID=1213&DID=7713&CTYPEID=113)

Over 50 *Tech Briefs,* four-page fact sheets produced by the National Environmental Services Center focusing on drinking water treatment issues, are archived at http://www.nesc.wvu.edu/techbrief.cfm. Some are available in both Spanish and English.

The National Drinking Water Clearinghouse Fact Sheet on disinfection compares the advantages and limitations of several different water disinfection processes, along with details on the process, equipment, and chemicals of each. (http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB1_Disinfection.pdf)

The National Drinking Water Clearinghouse Fact Sheet on ultraviolet disinfection provides in-depth information on the process and how it works. (http://www.nesc.wvu.edu/pdf/dw/publications/ontap/2009_tb/ultraviolet_dwfsom53.pdf)

The webpage "Chlorine chemistry: 100 years of safer lives" has links to several articles on the history of using chlorine for water disinfection, along with a clean water challenge quiz. (http://www.americanchemistry.com/100years/)

The American Chemistry Council offers a coloring and activity book “Water Germs Busted by Chlorine!”, available at http://www.americanchemistry.com/s_chlorine/doc.asp?CID=1197&DID=4544.

More sites on disposal of pharmaceuticals

The 2008 *Chemical & Engineering News* article “What To Do With Your Unused Pharmaceuticals” focused on the ongoing trend to dispose of pharmaceuticals in the toilet and discussed new guidelines. (http://pubs.acs.org/cen/coverstory/86/8608coverbox.html)

The Teleosis Institute lists take-back programs and/or resources available in various states, as well as on the national and international levels at http://www.teleosis.org/gpp-national.php. They also offer a search for medicine take-back locations by zip code (http://www.teleosis.org/gpp-locations.php).

A blog post describes how high school students “are taking the lead in a program to help eliminate discarded pharmaceuticals from rivers and streams in the United States.” (http://p2d2news.blogspot.com/2010/09/antioch-students-help-residents-discard.html)

One guide for organizing and running a pharmaceutical take-back event is available from the Idaho Office of Drug Policy at http://odp.idaho.gov/Prescription Drug Take-Back Program/Pharmaceutical Takeback Program Guide.pdf.

More Websites on Teacher Information and Lesson Plans [optional] (sites geared specifically to teachers)

The Illinois-Indiana Sea Grant College Program offers *The Medicine Chest*, a downloadable “compilation of multidisciplinary, standards-based classroom lessons, sample stewardship activities, and background information for teachers and high school students on how the improper disposal of unwanted medicines can be harmful to people, pets, and the environment.” (http://www.iisgcp.org/education/safe_disposal_curriculum.html)

Cleaning Up the Air

Background Information (teacher information)

More on the atmosphere and the future of coal

When considering the situation for the atmosphere and the increasing levels of a number of gases that are associated with global warming trends, there is the obvious connection between the production and combustion of various fuels for energy production and the rise in such things as carbon dioxide and methane. In particular, there is a desire to move away from carbon-based fuels such as coal, natural gas and petroleum-based derivatives for so-called alternative energy sources including nuclear, wind, solar (photovoltaic and thermal), and biomass among others. But crunching the numbers does not support the idea that we can replace a majority of the carbon-based fuels with alternatives. Sticking with something like coal, which is the driving force behind electricity production, is probably not the best idea, as this fuel has a bad reputation as a dirty fuel that is most often cited as a major contributor to global warming because of the high levels of carbon dioxide produced in the combustion process. Yet we can't just stop using coal. Looking forward, there is the problem of how to continue to use coal while significantly reducing the amount of carbon dioxide that gets into the atmosphere.

Ironically, it is this quest for a cleaner coal that has brought together two of the biggest carbon dioxide polluters, the US and China. (Together the two countries contribute 40 % of the world-wide annual output of carbon dioxide.) And in focusing on coal and the reduction of carbon dioxide production, it has made the argument more compelling that we will have to find ways to live with dirty coal while trying to prevent an ecological catastrophe of excessive global warming.

The data is very clear that we have gone from levels of carbon dioxide of about 280 ppm of dry air in the 18th C to something like 300 ppm in the early 20th C to a current level of 390 ppm. If the trend continues, carbon dioxide levels are expected to exceed 400 ppm in another 6 years. Utility companies both in China and the US accept the fact that these greenhouse gas emissions are an emergency that must be confronted, regardless of the doubters who question the cause and effect of carbon dioxide levels and global warming.

Through cooperative research between the US and China, there is a concerted effort to find ways to control the output of carbon dioxide emissions from electricity-generating plants. The goal is to prevent carbon dioxide emissions from raising atmospheric levels to a critical 500 ppm in the next 50 years (twice that of the pre-industrial age) which translates to reducing current levels of emission by 25 billion tons each year. It is suggested by one study group to look at the reductions through a series of "wedges" that focus on different areas that contribute carbon dioxide and how to reduce each contribution. One such wedge has to do with efficiency, another with renewable power, a third with avoiding deforestation and changing agricultural practices. But none of this eliminates the use of coal itself. For instance, currently a single coal mine in Kentucky (Cardinal Mine) supports roughly twice as much electricity generation as all the solar and wind facilities in the US, which illustrates how difficult in the future it will be to eliminate coal in the energy mix in favor of alternatives. Another point of illustration is the calculation by a Cambridge (England) physicist that if the windiest 10 percent of the entire British landscape were completely covered with wind turbines, the turbines would produce power equivalent to half of what Britons expend just on driving each day. Again the argument is being made through calculations that it will be very difficult to get rid of coal as a primary fuel in the next 50 years. Therefore, it is necessary to find ways to reduce significantly how much carbon dioxide gets into the atmosphere from the combustion of coal. The top four coal-reserve countries are the United States, Russia, China and India. These countries have 40 percent of the world's population and 60 percent of the coal reserves.

In trying to find answers to curtailing the effects of using dirty coal, proposals focus on two approaches—pre-combustion control and post-combustion control of carbon dioxide emissions. In each approach, the carbon dioxide that is prevented from entering the atmosphere must still be "disposed of" through the technique of "sequestering" or putting the carbon dioxide into a physical location other than the atmosphere. In particular we are talking about injecting carbon dioxide into rock formations, salt mines, abandoned oil deposits, and the ocean.

See another analysis of the time frame for reducing atmospheric carbon dioxide levels at http://www.scientificamerican.com/article.cfm?id=how-fast-can-carbon-capture-and-storage-fix-climate-change. The comments that follow this suggested article are even more interesting in terms of the understanding and personal bias of the public.

More on clean-burning coal

In the last 10–15 years, technologies have continued to be developed that reduce the level of pollutants that come from the burning of coal, including carbon dioxide and mercury. One of these technologies mentioned in the article is called "integrated gasification combined cycle" (IGCC). Improvements on the basics of this process are occurring in Germany, using what is called "Oxyfuel Technology." The important difference compared with standard IGCC is the use of nearly pure oxygen with the coal, rather than the traditional air/coal mix.

In the first stage, air separation removes nitrogen (78% of the air mixture), leaving nearly pure oxygen. Then a stream of pulverized coal and this oxygen is blasted into a water boiler. The coal that is pulverized is previously "washed", by which the coal passes through a series of liquids with varying densities (the impurities sink in the liquids). The coal/oxygen mix burns at a higher temperature in the boiler than a coal/air mix, which actually allows a second use of the hot gas mixture (primarily carbon dioxide and water vapor). The mixture is returned to the boiler for a second heating and more steam generation. The escaping gases from the boiler area (flue gases) are put through a series of chemical treatments before being released into the atmosphere.

Because the nitrogen was removed in the pre-combustion stage, nitrogen oxides are not formed. But the exhaust gases contain very small particles called fly ash that are removed. This is usually done with electrostatic precipitators. Sulfur dioxide, which is responsible for creating acid rain, is removed by flue gas desulphurization (FDG). This process uses a mixture of limestone [$Ca(OH)_2$] and water that is sprayed over the flue gas. The reaction forms $CaSO_4$, or gypsum, which can be used in construction (to make dry wall). (You may recall that dry wall imported from China has caused the construction industry much grief as it was highly acidic (sulfur compounds) and caused structural damage in many homes and commercial buildings.)

In the final filtering stage, the flue gas is cooled to condense the water vapor. What remains in the gas stream is nearly pure carbon dioxide. This carbon dioxide is then compressed into a liquid state. A pressure of some 70 atmospheres produces a liquid carbon dioxide of the density of crude oil which makes it more efficient to transport. (http://news.bbc.co.uk/2/hi/science/nature/7586569.stm)

More on carbon dioxide capture and storage (sequestration)

There are many questions about the environmental safety of sequestering of carbon dioxide gas. There are several proposed or actual repositories, including the oceans and various geological formations. For some statistics, data published by the Dakota Gasification Company (Bismarck, ND) include the following:

Dakota Gas captures about 3 million tons of CO_2 per year.
Up to 50% of the CO_2 is captured each day the plant is operating.
Dakota Gas ships about 8,000 metric tons of CO_2 daily.
Since 2000, CO_2 emissions at the Synfuels Plant have been reduced by about 45%.
As of Dec. 31, 2008, Dakota Gas had captured more than 16 million tons of CO_2.

Dakota Gas sends the carbon dioxide through a 205-mile pipeline to Saskatchewan, Canada, where oil companies use it for enhanced oil recovery operations that result in permanent carbon dioxide sequestration. (http://www.dakotagas.com/CO2_Capture_and_Storage/index.html) This is a win-win situation, as the oil companies pay Dakota Gas for the carbon dioxide. This may not be a feasible solution going forward, since the value of carbon dioxide will drop drastically as more companies capture their own carbon dioxide and liquefy it and then try to find places to put it.

More on geological sequestration

Geological sequestration includes oil and gas reservoirs, coal seams, and deep salt reservoirs. Research continues to look at the way in which CO_2, once sequestered, moves within the geological formations. There is also interest in what chemical, as well as physical, changes take place when the gas is injected into a reservoir. It is known, as mentioned above, that injecting carbon dioxide gas into oil and natural gas reservoirs that are running low can assist in additional oil and gas recovery where flows have peaked. This is known as enhanced recovery. But it is important that the carbon dioxide pressures not exceed those of the original pressure in the reservoir in order to keep the gas in the geological formation. Recovering additional oil and gas from these reservoirs using the carbon dioxide gas means that the revenues from the recovered fuels help to offset the cost of sequestering the gas (from source to destination).

In the case of coal bed methane, carbon dioxide can be used to “push out” the methane gas that is adsorbed on the coal. Currently, methane is recovered from coal seams by lowering the pressure within the mine, usually by pumping out water. It has been found that if carbon dioxide gas is pumped into these methane-laden coal beds, the gas is adsorbed twice as fast as methane, meaning that the adsorbed carbon dioxide will physically displace the methane. And of course the carbon dioxide remains in the coal bed. It is estimated that US coal resources total some 6 trillion tons and 90% of it is currently not minable due to seam thickness, depth, and structural integrity. Since many of these un-minable coal seams are near electric generating plants that use coal, it is a win-win situation with the sequestering of the carbon dioxide and the recovery of methane gas that could be integrated in the coal-fired plant as an additional power generation option.

Depositing carbon dioxide into salt formations does not produce the kind of value-added by-products as with oil and coal sequestering. But it is still a useful reservoir because of the total capacity—something on the order of 500 billion tons of CO_2. Also, it seems as though most carbon dioxide generating plants are close to a saline formation, reducing costs of transport. But much more research needs to be done to determine the extent to which injected carbon dioxide remains in the salt and does not infiltrate water supplies or migrate up to the earth's surface. Some data is available from the injection of brine into oil recovery operations, as well as from the current practice of injecting some one million tons of carbon dioxide per year into a salt formation under the North Sea. (http://www.fossil.energy.gov/programs/sequestration/geologic/index.html) This reference also includes an interactive geologic sequestration model.

More on terrestrial sequestration of carbon dioxide

The use of soil and vegetation for carbon dioxide sinks is a natural choice since the worldwide biosphere is thought to absorb about 2 billion tons of CO_2 annually. This is about one-third of global carbon emissions from human activity. It is estimated that soil and plant roots have in storage about 2 trillion tons of carbon (equal to 1,000 years of annual absorption). This sequestration is described as either the removal of carbon dioxide from the atmosphere or the prevention of the escape of CO_2 from the soil and plants into the atmosphere. It is the removal aspect that is thought to be the best way to reduce atmospheric CO_2. Therefore, maintaining forests (and prevention of their loss) is paramount to this particular sequestration process. Looking at ecosystems for sequestration, the following are important components of that process:

Forest lands. The focus includes below-ground carbon and long-term management and utilization of standing stocks, understory, groundcover, and litter.

Agricultural lands. The focus includes crop lands, grasslands, and range lands, with emphasis on increasing long-lived soil carbon.

Biomass croplands. As a complement to ongoing efforts related to biofuels, the focus is on long-term increases in soil carbon and value-added organic products.

Deserts and degraded lands. Restoration of degraded lands offers significant benefits and carbon sequestration potential in both below- and above-ground systems.

Boreal wetlands and peat lands. The focus includes management of soil carbon pools and perhaps limited conversion to forest or grassland vegetation where ecologically acceptable.
http://www.fossil.energy.gov/programs/sequestration/terrestrial/index.html

More on methane

Methane (CH_4) is the primary component of natural gas and an important energy source. Methane is also a greenhouse gas, meaning that its presence in the atmosphere affects the Earth's temperature and climate system. Due to its relatively short life time in the atmosphere (9–15 years) and its global warming potency—20 times more effective than carbon dioxide (CO_2) in trapping heat in the atmosphere—reducing methane emissions should be an effective means to reduce climate warming on a relatively short timescale.

Human-influenced sources of methane include landfills, natural gas and petroleum production and distribution systems, agricultural activities, coal mining, stationary and mobile combustion, wastewater treatment, and certain industrial processes. About 60% of global methane emissions come from these sources and the rest are from natural sources (IPCC, 2001). Natural sources include wetlands, termites, oceans, and hydrates (which consist of methane molecules each surrounded by a cage of water molecules and are present in seafloor deposits around the world).

The historical record, based on analysis of air bubbles trapped in ice sheets, indicates that methane is more abundant in the Earth's atmosphere now than at any time during the past 400,000 years (IPCC, 2001). Over the last two centuries, methane concentrations in the atmosphere have more than doubled. However, in the past decade, while methane concentrations have continued to increase, the overall rate of methane growth has slowed. Given our incomplete understanding of the global methane budget, it is not clear if this slow down is temporary or permanent.

Once emitted, methane is removed from the atmosphere by a variety of processes, frequently called "sinks." The balance between methane emissions and methane removal processes ultimately determines atmospheric methane concentrations, and how long methane emissions remain in the atmosphere. The dominant sink is oxidation by chemical reaction with hydroxyl radicals (OH).

U.S. government programs to reduce atmospheric methane concentrations have led to emissions reductions of about 10% below 1990 levels (EPA, 2005). These voluntary programs have targeted methane reductions in coal mining, landfills, oil and natural gas systems, and agriculture by more effectively capturing methane during fossil-fuel extraction, capturing methane from landfills, and reducing biomass burning.
http://www.climatescience.gov/infosheets/highlight1/default.htm#Dlugokencky

An interesting aside is the role of ruminants in producing and belching methane that is produced in the anaerobic digestion of plant matter. Statistics provide some scope to the extent of the problem worldwide. http://www-naweb.iaea.org/nafa/aph/stories/2008-atmospheric-methane.html

More recent concerns center on the Arctic new releases of methane due to warming trends and the melting of ice coverings over land that has methane generated from biomass decay. http://www.csmonitor.com/Science/2010/0304/Global-warming-Scientists-find-methane-source-in-Arctic-seas

More on carbon dioxide and environmental acidity

Article on changes in ocean (Alaska) acidity—
http://www.csmonitor.com/Environment/Global-Warming/2009/1204/global-warming-increases-acidity-in-alaskan-seas. The article deals with the increase in acidity in the oceans from increases in carbon dioxide, the twin of the effect on the atmosphere's climate. It expresses concern for the depletion of minerals in the ocean that are part of the total picture for productivity of sea life. The alkaline-acid balance continues to be tipped toward the acidic range. There is a limit to how much neutralization can be done by calcium and magnesium carbonate. And the pH changes affect the food chain in terms of shelled organisms that depend on calcium carbonate.

More on global warming and changes in atmospheric CO_2 levels

This article summarizes the need to reduce CO_2 levels and the evidence for global warming: http://www.csmonitor.com/USA/2009/1125/p02s01-usgn.html.

More on analysis of historical record for atmospheric gases

How do scientists determine temperatures and levels of various atmospheric gases back in the times of the industrial revolution and even millennia before that? One of the principle tools is the analysis of ice cores that have revealed a variety of atmospheric events back to 420,000 years ago. These cores extend to 3,600 meter (2.2 miles) below the surface in places like the Vostok site in Antarctica and Greenland. To determine past temperatures (on a comparative scale), gases trapped in the ice core samples are analyzed for their concentration of deuterium versus normal hydrogen in water. The more deuterium in a sample, the warmer the climate when the sample was deposited. During very cold temperatures, a great deal of the heavier hydrogen isotopes has "rained out" *—what is left is isotopically depleted or lighter. Snow from colder periods has less of the heavier isotopes of hydrogen (and oxygen). So, warming trends or the reverse can be detected. In addition, gases trapped can be released from a sample and analyzed for their composition and concentration. Data clearly shows that current carbon dioxide levels are higher (28 %) than they have been in 440,000 years. A nice graph that shows the relation between carbon dioxide concentrations and temperature over this time period can be seen at http://www.daviesand.com/Choices/Precautionary_Planning/New_Data/. There is also some discussion about this data and its implications at this same site. A second composite graph of temperature, carbon dioxide, and dust concentrations correlated with time (estimated years) is found at http://en.wikipedia.org/wiki/File:Vostok_Petit_data.svg

[* "The classic paleothermometer is the stable-isotopic composition of water in the ice core. Natural waters typically contain a fraction of a percent of isotopically heavy molecules (in which the hydrogen or oxygen contains one or two "extra" neutrons). The vapor pressure of this heavy water is less than for "normal" light water. As an air mass is cooled and precipitates, it preferentially loses heavy water and must increasingly precipitate light water. At very low temperatures, heavy water has been greatly depleted and precipitation is isotopically light. Empirically and theoretically, isotopic composition of precipitation and site temperature are strongly correlated in time and space; colder places and colder times have isotopically lighter precipitation."] http://www.pnas.org/content/97/4/1331.full—full description of techniques for dating and interpretation.

Analysis of the cores can also provide evidence of other events that can influence temperature and atmospheric composition including volcanic eruptions (dust deposits in ice core plainly visible), Some good photos of ice cores clearly showing the annual layers is found at http://en.wikipedia.org/wiki/Ice_core

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Endothermic reaction**—The recycling of carbon (carbon cycle) includes an endothermic reaction called photosynthesis in which the net energy input is from solar radiation. The energy becomes part of the potential energy of the bonds found in the products, a carbohydrate such as glucose and oxygen molecules.
2. **Exothermic reaction**—The recycling of carbon (carbon cycle) utilizes an exothermic reaction in the form of respiration in which the carbon contained in a glucose molecule is converted to carbon dioxide, which is recycled back through photosynthesis. This respiration reaction is a net energy gain that is passed through another series of reactions, transferring the energy to bonds in the molecule adenosine triphosphate (ATP) which in turn "drives" biological processes that require energy.

3. **Molecular vibrational frequencies**—various molecules such as carbon dioxide (CO_2), methane (CH_4), water (H_2O), and nitrous oxide (N_2O) have natural vibrational frequencies that match those vibrations of infrared and ultraviolet light, hence can absorb those particular electromagnetic radiations, producing the greenhouse effect when that form of energy is transformed into thermal energy.
4. **Bond energies**—The carbon cycle depends on the sum total of bond energies involved in both the breaking as well as the making of bonds in the conversion of carbon dioxide and water to glucose and oxygen molecules in photosynthesis and the reverse reaction in respiration.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"Sunlight is naturally very hot because it comes from the hot sun, creating global warming."** *For heat to be coming from the sun, it would require an atmosphere (a mass) from the sun to earth for heat transfer (atmospheric gases with mass). What is transmitted is electromagnetic radiation that, when absorbed by certain molecules in the atmosphere surrounding the earth (and not extending all the way into outer space), becomes thermal energy (atoms or molecules vibrating faster which means an increase in temperature).*
2. **"Photosynthesis is an exothermic reaction because the sun's energy is involved "** *Photosynthesis is an endothermic reaction because the sun's energy is utilized in the synthesis of glucose—net energy change is positive or endothermic. More energy is used for bond breaking in carbon dioxide and water molecules than is released in bond making of glucose and oxygen.*
3. **"Breaking bonds in a chemical reaction such as in respiration is exothermic—energy released."** *To break bonds in a molecule requires an increase in the potential energy of the bonds (atoms within the molecule must become further apart until the electrostatic forces between atoms are weakened enough through an increase in distance). Bond breaking therefore is endothermic. The overall reaction of respiration which requires both breaking and making bonds is an exothermic reaction but not from the breaking of bonds alone.*

Anticipating Student Questions (answers to questions students might ask in class)

1. **"How is it possible to keep carbon dioxide gas sequestered underground—won't it escape to the surface?"** *One example of carbon dioxide sequestering is in Norway where the captured CO_2 is injected into sandstone formations under the ocean which formerly housed natural gas formations. "An 800-foot (250-meter) thick band of sandstone—porous, crumbly rock that traps the gas in the minute spaces between its particles—is covered by a relatively impermeable 650-foot (200-meter) thick layer of shale and mudstone (think: hardened clay). The integrity of this system (that is, the trapping of the gas) is not in doubt." (http://www.scientificamerican.com/article.cfm?id=storing-fossil-fuel-carbon-deep-underground). See also this reference for more details on sequestering and prevention of leakage of carbon dioxide at http://www.scientificamerican.com/article.cfm?id=storing-fossil-fuel-carbon-deep-underground*
2. **"Frequently asked questions about global warming and 'conspiracy theories' about climate scientists" are found at the following reference, which is a good collection of**

questions and responses. *See http://co2now.org/Know-the-Changing-Climate/Climate-FAQs/.*

In-class Activities (lesson ideas, including labs & demonstrations)

1. Students can be shown the ease with which an acid reacts with magnesium carbonate and calcium carbonate in rock to generate carbon dioxide (the reverse reaction of the formation of the carbonates mentioned in the article for sequestering carbon dioxide). The sequestering reaction with magnesium silicate for instance is:
   $Mg_2SiO_4 + 2\,CO_2 \rightarrow 2\,MgCO_3 + SiO_2$
   Using the $MgCO_3$ from this reaction to show the reaction of the acid on the carbonate rock to produce CO_2 would be
   $MgCO_3 + 2\,H^+ \rightarrow Mg^{+2} + CO_2 + H_2O$
   Using marble chips in a 500 ml flask with a side arm delivery tube, add 6M hydrochloric acid to the marble chips (use a thistle tube in a rubber stopper fitted to the flask mouth and positioned so it will be below the level of the acid after it is added). A rubber delivery tube can be used to bubble carbon dioxide into a flask with lime water [$Ca(OH)_2$] to show a positive reaction for the presence of the gas. A related point of discussion would be the effect of acid rain (in part, from carbon dioxide in the air as well as other gases such as the nitrogen and sulfur oxides from combustion of fossil fuels) on stone structures.
2. Testing for carbon dioxide gas: exhale into lime water. Also generate carbon dioxide gas and oxygen gas and bubble into lime water to differentiate between the two gases present in exhaled air.
3. Formation of acidic water by bubbling carbon dioxide gas through water. Use of pH indicators. (Bromothymol blue).
4. You can show the interaction of photosynthesis and respiration in a water system using test tubes with caps, aquatic plants such as *Elodea.* Set up for the tubes:
   a. CONTROL= no plant, bromothymol blue (BThB) indicator, distilled water plus cap; bubble exhaled air into the tube until water turns yellow (pH 6.0).
   b. VARIABLE = tube with plant, BThB, distilled water, plus cap: bubble exhaled air into each test tube with a straw until the solution turns yellow (acid). If the solution is yellow before bubbling, add drop-wise, a dilute solution of ammonia hydroxide (NH_4OH) until the solution turns blue (pH 7.0).

   Place tubes so that they receive light (preferably fluorescent light). Students will relate the change in pH to the presence or absence of carbon dioxide and the function of the plants in affecting the pH or sampling carbon dioxide at http://www.accessexcellence.org/MTC/96PT/Share/culp.php.
5. Pouring carbon dioxide gas to snuff out a candle; idea of gas density. Use tubing attached to a side-arm flask. Generate gas using baking soda and vinegar. If dry ice is available, place in a beaker, allow to sublimate and pour the gas over the candle.
6. Reactions of carbonates (magnesium and calcium) with different acids: students could sample various carbonate sources with acids of different strength such as acetic acid vs. carbonic acid vs. hydrochloric acid, all at 0.1M. Relate these reactions to the effect of acid rain on stone structures involving marble and limestone.
7. Different kind of reaction with carbon dioxide gas: place a burning piece of magnesium metal in a jar containing carbon dioxide gas (generated in a flask with side arm for gas delivery into the jar or beaker; use marble chips and hydrochloric acid or vinegar and baking soda). The redox reaction changes carbon dioxide into carbon and magnesium oxide.
   $2\,Mg\,(s) + CO_2\,(g) \rightarrow 2\,MgO\,(s) + C\,(s)$

The carbon is visible as black flakes.

8. Students can do a simple experiment to generate carbon dioxide gas and show its ability to be poured because of its higher density than air. In the experiment, pouring the gas on a lit candle extinguishes the flame. You could use this as a demo to generate some questions to test student use of relevant ideas about why the flame is extinguished—lots of interesting thoughts come from students on this demo! See Becker, R. A Pourable Greenhouse Gas. *ChemMatters*, **2001**, *19* (3), pp 10–11. (Also available free online at http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_SUPERARTICLE&node_id=2119&use_sec=false&sec_url_var=region1&__uuid=3c57bd2f-91e0-4a2f-b532-1727071f0fe0. Scroll down to September, 2001 and click on the icon.)
9. The whole topic of global warming and the manner by which carbon dioxide, as well as methane, can contribute toward this environmental hazard is a series of lessons that are crucial for student understanding of the warming phenomenon. There is lots of global temperature data for the last century that would make an interesting starting point for classroom discussion. There is the question of a correlation between atmospheric carbon dioxide levels versus increases in global temperatures. And from that follows the issue of cause and effect—do increasing levels of carbon dioxide and the rise of average global temperatures mean a "cause and effect"? Students can research the scientific arguments (versus political arguments) for and against a "cause and effect" proposition. The issue of sequestering carbon dioxide from the combustion of fossil fuels raises one question having to do with the ability of an ocean system, for instance, to absorb the carbon dioxide without catastrophic chemical changes to the water system that would negatively impact on the ocean ecosystem (living, non-living). A demonstration can be done in which carbon dioxide gas (generated from hydrochloric acid and limestone or marble chips) can be bubbled into water (with universal indicator), showing the change in pH when the carbon dioxide reacts with water to form carbonic acid, an equilibrium situation. Next step is to mimic some neutralization of the acidic condition using a weak basic solution such as 0.1 M NaOH solution. The reacting/dissolving of the limestone can also be used to illustrate the effect of an acidic ocean on something like a coral reef or on various shelled organisms that have limestone as the major structural component of those shells. (A good description of this chemistry specific to the ocean can be found at http://www.realclimate.org/index.php/archives/2005/07/the-acid-ocean-the-other-problem-with-cosub2sub-emission/.
10. How have coal and oil formed? Students generally have little understanding or knowledge about the formation of coal and oil deposits. A good source of such information, with photos, is found at http://geology.com/rocks/coal.shtml .

Out-of-class Activities and Projects (student research, class projects)

1. Research data on carbon dioxide levels in the atmosphere over the last 100 years; relate to average temperatures of the atmosphere over the last 100 years. What other factors might contribute to the rise in temperatures in the last 100 years? Students can graph both sets of data on the same graph for comparison. (They will need to do their own online research to find average yearly temperatures for this same range of years.) Does a correlation mean a cause and effect? What other data and types of information are needed to get to a cause and effect?

YEAR	**Approximate CO_2 Level**

	(ppm by volume)
1900	287
1920	303
1930	310
1960	317
1965	320
1970	325
1972	328
1974	330
1976	332
1978	335
1980	338
1982	341
1984	344
1986	347
1988	351
1990	354
1992	356
1994	358
1996	363
1998	367

The data above can be graphed and students could extrapolate to see what levels might be attained in the next 50 years. What is the critical limit for atmospheric carbon dioxide before the earth is in catastrophe mode, according to scientists? What are the limits to extrapolation of the data?

Several references with data and graphs relating CO_2 and average global temperature include:
http://www.ncdc.noaa.gov/paleo/globalwarming/instrumental.html ,
http://myplace.frontier.com/~vze7z6xj/WVFossils/temp_vs_CO2.html,
http://co2now.org/Current-CO2/CO2-Now/global-temperature-update.html
http://www.whole-systems.org/co2.html (collection of graphs with temperature and CO_2)
http://zfacts.com/p/226.html (clear graph of temperature vs. CO_2, 1880 to 2005)
and http://myplace.frontier.com/~vze7z6xj/WVFossils/last_100_yrs.html

An all-in-one place for data, graphs and explanations related to global temperatures, carbon dioxide levels, ice core and ocean heat content among others is found at http://climateprogress.org/2010/04/14/the-complete-guide-to-modern-day-climate-change/

2. Students could model the effect of carbon dioxide gas on atmospheric warming by setting up two identical 10–15 gallon fish tanks in which you generate carbon dioxide gas by reacting baking soda with vinegar in the bottom of the tank. An incandescent bulb above the tank cover is the source of IR.—you could use several show-case lights. A digital thermometer records the temperature at two levels in the tank—just above the liquid and midway up the tank. The control tank has everything except no extra carbon dioxide generated. Temperature readings are taken over a 5–10 minute period (have to experiment) in both tanks.
3. Some experiments involving carbon dioxide effects on both terrestrial and water environments (using soda bottles or aquariums) are clearly set out at http://www.co2science.org/education/experiments/global.php.

4. What does the data obtained from ice core sampling show about the concentrations of atmospheric greenhouse gases over the millennia? http://www.newscientist.com/article/dn11659-climate-myths-ice-cores-show-co2-increases-lag-behind-temperature-rises-disproving-the-link-to-global-warming.html and http://www.daviesand.com/Choices/Precautionary_Planning/New_Data/ provide real data on the concentration in ice cores of various greenhouse gases, in particular carbon dioxide, and their implications for global warming trends, past and future. A most comprehensive reference on all aspects of global warming—the data, the collection techniques, the implications can be found at http://www.global-climate-change.org.uk/contents.php.

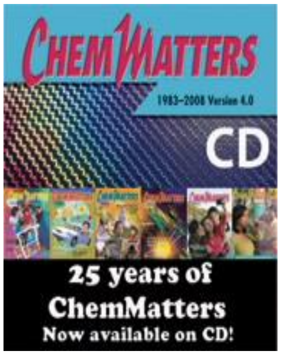
References (non-Web-based information sources)

Chemistry in Context, from the American Chemical Society, is a good reference text with accompanying laboratory manual that can be used for lab exercises dealing both with energy from a variety of fuels and the combustion products that contribute to air pollution. The background reading from the text complements the lab exercises, although the text, written at a college level, is more for the teacher than the average student. A description of the materials and purchase information can be found at the ACS web site: http://portal.acs.org:80/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_SUPERARTICLE&node_id=560&use_sec=false&sec_url_var=region1&__uuid=c185679a-2559-426f-b79c-bb1e6288bc1a . The textbook can also be purchased at amazon.com.

Fallows, J., Dirty Coal, Clean Future. *The Atlantic,* December, 2010, pp 64–78.

Stanitski, C. L.; Eubanks, L. P.; Middlecamp, C. H.; Stratton, W. J. *Chemistry in Context: Applying Chemistry to Society*, 3rd ed.; American Chemical Society: Washington, DC, 2000.

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for $30 (or a site/school license is available for $105) at this site: http://www.acs.org/chemmatters. (At the bottom of the Website screen, click on the *ChemMatters* CD image like the one at the right.)



Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Barnwell, G. Your Personal Greenhouse. *ChemMatters,* **1990,** *8* (4), pp 8–10. This is a good reference for specific data on how much an individual contributes to the CO_2 in the atmosphere, through the use of electrical appliances and transportation.

Banks, P. Ice That Burns. *ChemMatters,* **1995,** *13* (3), pp 8–11. This article deals with an unusual source of methane in the form of ice found at the bottom of oceans and in the permafrost. It represents a good energy source from ocean deposits. But if global warming continues to melt the permafrost its methane will be released into the atmosphere without being captured as a fuel, adding to the warming problems.

Cardulla, F. Global Warming: A Hot Topic Getting Hotter. *ChemMatters,* **2001,** *19* (3), pp 14–15. This particular article discusses the various opinions about global warming and its effects. It provides evidence for projecting a continuing trend using various mathematical models and states their limitations.

Herlocker, H. Life in a Greenhouse. *ChemMatters,* **2003**, *21* (3), pp 18–21. This is a good article that explains the relationship between the various wavelengths of EMR and their interaction with the various greenhouse gases. There is also a chart comparing the various greenhouse gases to the reference gas, CO_2, in terms of relative effectiveness for absorbing IR.

Becker, R. A Pourable Greenhouse Gas. *ChemMatters*, **2001**, *19* (3), pp 10–11. This is a description of a simple experiment for generating carbon dioxide gas and showing its ability to be poured because of its higher density than air. In the experiment, pouring the gas on a lit candle extinguishes the flame. You could use this as a demo to generate some questions to test student use of relevant ideas about why the flame is extinguished—lots of interesting thoughts come from students on this demonstration!

Websites for Additional Information (Web-based information sources)

More sites on government information about climate change can be found at:

http://epa.gov/climatechange/index.html (climate change)

http://www.epa.gov/methane/scientific.html (methane)

http://epa.gov/climatechange/emissions/usinventoryreport.html—an extremely comprehensive listing (reports) for greenhouse gases from a plethora of sources besides just burning of fuels

http://epa.gov/climatechange/indicators.html (climate change indicators)

http://epa.gov/climatechange/indicators/pdfs/CI-summary.pdf (all-in-one-place summary of the effects of global warming on all aspects of climate change and contributing factors. It includes a slide show that can be used in class.)

More sites on sequestering carbon dioxide

A series of five articles from the *Scientific American* that discusses the various dimensions to carbon capture and storage can be found at http://www.scientificamerican.com/article.cfm?id=how-fast-can-carbon-capture-and-storage-fix-climate-change.

Photographs of carbon capture and storage equipment can be found at http://www.scientificamerican.com/article.cfm?id=what-does-carbon-capture-and-storage-look-like.

The storage of carbon dioxide in a project in the North Sea is described and illustrated at http://www.scientificamerican.com/article.cfm?id=storing-fossil-fuel-carbon-deep-underground.

A similar proposal to bury carbon dioxide in the oceans using volcanic formations off the coast of the USA is described at http://www.scientificamerican.com/article.cfm?id=undersea-carbon-capture-and-storage. This particular reference includes a discussion on the limits to such a procedure.

A reference on an actual sequestering operation in which the carbon dioxide produced by a utility company is sold to and used by an oil company for enhanced oil recovery operations is found at http://www.dakotagas.com/CO2_Capture_and_Storage/index.html.

Some data is available from the injection of brine into oil recovery operations, as well as from the current practice of injecting some one million tons of carbon dioxide per year into a salt formation under the North Sea.
http://www.fossil.energy.gov/programs/sequestration/geologic/index.html—this reference also includes an interactive geologic sequestration model.

More sites on clean burning coal

This web site discusses a unique carbon capture and storage power plant in Germany in which something called oxyfuel is produced from coal. There is a nice illustration of the physical setup for the process and a clear description of each stage in the process. If this process succeeds, it would make coal truly a clean fuel.
(http://news.bbc.co.uk/2/hi/science/nature/7586569.stm)

More sites on carbon dioxide and environmental acidity

The reference that follows deals with the increase in acidity in the Alaskan oceans from increases in carbon dioxide, the twin of the effect on the atmosphere's climate. It expresses concern for the depletion of minerals in the ocean that are part of the total picture for productivity of sea life. The alkaline-acid balance continues to be tipped toward the acidic range. There is a limit to how much neutralization can be done by calcium and magnesium carbonate. And the pH changes affect the food chain in terms of shelled organisms that depend on calcium carbonate. (http://www.csmonitor.com/Environment/Global-Warming/2009/1204/global-warming-increases-acidity-in-alaskan-seas)

More sites on global warming and changes in atmospheric CO_2 levels

The article that follows summarizes the need to reduce CO_2 levels and the evidence for global warming: http://www.csmonitor.com/USA/2009/1125/p02s01-usgn.html.

A most comprehensive reference on all aspects of global warming—the data, the collection techniques, the implications can be found at http://www.global-climate-change.org.uk/contents.php.

A series of PBS programs (video) on global warming can be found at http://www.pbs.org/now/shows/304/ and http://myvideo-zoolander.blogspot.com/2009/05/pbs-nova-global-warming-whats-up-with.html.

More sites on data from ice core sampling

What does the data obtained from ice core sampling show about the concentrations of atmospheric greenhouse gases over the millennia? http://www.newscientist.com/article/dn11659-climate-myths-ice-cores-show-co2-increases-lag-behind-temperature-rises-disproving-the-link-to-global-warming.html and http://www.daviesand.com/Choices/Precautionary_Planning/New_Data/ provide real data on the concentration in ice cores of various greenhouse gases, in particular carbon dioxide, and their implications for global warming trends, past and future.

More Websites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

http://epa.gov/climatechange/indicators/pdfs/CI-summary.pdf is an “all-in-one-place” summary of the effects of global warming on all aspects of climate change and contributing factors. It includes a ***slide show*** that can be used in class.

Kilimanjaro: Peering through Disappearing Ice

Background Information (teacher information)

More on climate change

A 2008 report on climate change from the National Academies of Science stated that "there is a growing concern about global warming and the impact it will have on people and the ecosystems on which they depend. Temperatures have already risen 1.4°F since the start of the 20th century—with much of this warming occurring in just the last 30 years—and temperatures will likely rise at least another 2°F, and possibly more than 11°F, over the next 100 years. This warming will cause significant changes in sea level, ecosystems, and ice cover, among other impacts. In the Arctic, where temperatures have increased almost twice as much as the global average, the landscape and ecosystems are already changing rapidly.

"Most scientists agree that the warming in recent decades has been caused primarily by human activities that have increased the amount of greenhouse gases in the atmosphere, gases, such as carbon dioxide, have increased significantly since the Industrial Revolution, mostly from the burning of fossil fuels for energy, industrial processes, and transportation. Carbon dioxide levels are at their highest in at least 650,000 years and continue to rise." http://dels-old.nas.edu/dels/rpt_briefs/climate_change_2008_final.pdf

Climate change refers to the long-term shift in average weather as a result of changes in the atmosphere-ocean-land system that affects a region's weather. Long-term changes in climate are actually normal. The Cretaceous period (120 million–90 million years ago) in North America was marked by vegetation that grows only in warm climates and was the age of dinosaurs. On the other hand, massive ice sheets prevailed about 21,000 years ago. In the last 650,000 years there have been seven cycles in which glaciers have advanced and retreated. These variations took place over long time periods and over large land masses. Students should not confuse climate change with unusual isolated local weather events, like snow in normally balmy regions.

Climatologists divide climate study into three time periods that are based on the kind of data used to study climate change. The instrumental era includes the last 150 years when accurate weather records are available. The historical era includes the records from all of human history. Much of the information available from this time period is not very precise, nor even quantitative, but it is actual data. The pre-historic era (or the period of paleoclimatology) relies on "proxy data" to infer changes in climate. See "More on paleoclimatology" for details.

The time scale used when talking about climate change is also important. There are long-term trends in climate as well as shorter periods of change. Climatologists usually use four time periods:

- Long term- *Hundreds of millions of years;*
- Medium term- *One million years;*
- Short term- *~160,000 years;*
- Modern period- Hundreds of years.

According to the U.S. Environmental Protection Agency, “Climate change is a term that refers to major changes in temperature, rainfall, snow, or wind patterns lasting for decades or longer. Both human-made and natural factors contribute to climate change:

- Human causes include burning fossil fuels, cutting down forests, and developing land for farms, cities, and roads. These activities all release greenhouse gases into the atmosphere.
- Natural causes include changes in the Earth’s orbit, the sun’s intensity, the circulation of the ocean and the atmosphere, and volcanic activity.

“Although the Earth’s climate has changed many times throughout its history, the rapid warming seen today cannot be explained by natural processes alone.

“Human activities are increasing the amount of greenhouse gases in the atmosphere. Some amount of greenhouse gases is necessary for life to exist on Earth—they trap heat in the atmosphere, keeping the planet warm and in a state of equilibrium. But this natural greenhouse effect is being strengthened as human activities (such as the combustion of fossil fuels) add more of these gases to the atmosphere, resulting in a shift in the Earth’s equilibrium.” (http://www.epa.gov/climatechange/downloads/Climate_Change_Science_Facts.pdf)

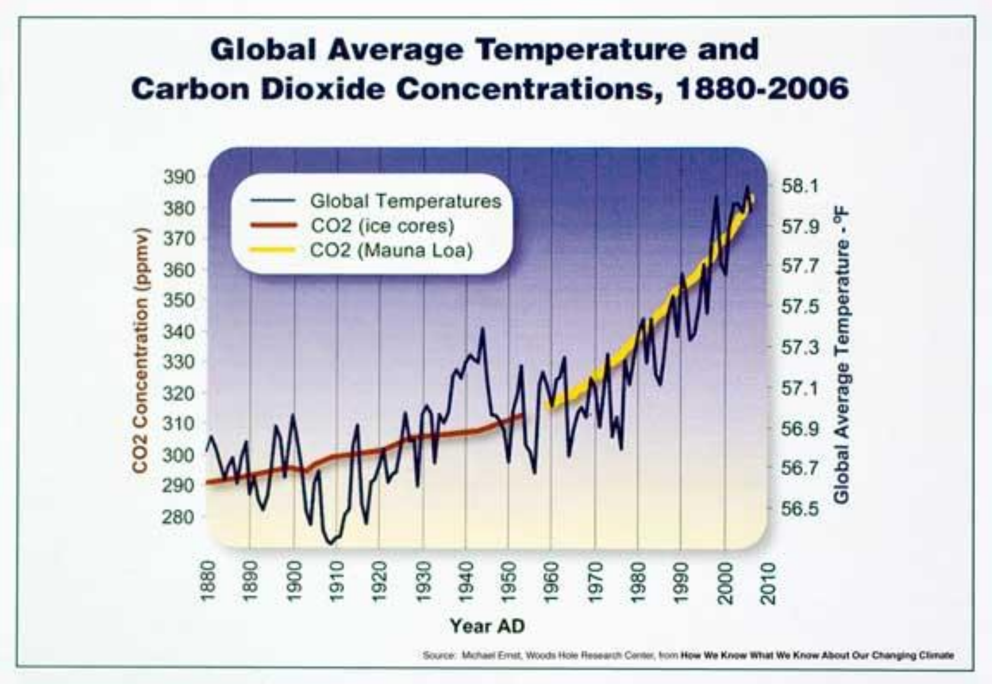
Where did the study of cyclic climate change originate and who developed it? The idea began as geologists became interested in the role of glaciers in geologic change. In the early 1800s Jean-Pierre Perraudin, a French non-scientist, noted that some of the rocks surrounding his home in the Alps were not like the majority. He also noted that scratch marks on the rocks must have been caused by glaciers as they carried the rocks down the mountains into the valley below. This idea that glaciers once extended into what was then a more moderate climate was widely rejected in the early 1800s. Perraudin eventually convinced several influential natural scientists, among them Louis Agassiz, who first set out an “Ice Age’ theory that glaciers periodically extended down from the North Pole to cover much of Europe and North America.

Eventual acceptance of the Ice Age theory in the late 1800s caused a great deal of debate. What caused the Ice Age and what caused it to end? Fossils from forests that existed in moderate climates were found in between layers from the Ice Ages, thus beginning a sustained interest in cyclic climate change.

Of much interest to chemistry students is the role that Svante Arrhenius (Arrhenius acid-base theory) played in developing another aspect of the climate change debate—the importance of carbon dioxide as a “greenhouse gas.” Arrhenius is, of course, best known in chemistry circles for his theories about electrochemistry, electrolytes, ions in solution, reactions in aqueous solution and the nature of acids and bases. Awarded a Nobel Prize in Chemistry for his electrochemistry work in 1903, Arrhenius also theorized that the drop in temperature that caused the ice age was due to a decrease in carbon dioxide (Arrhenius called it “carbonic acid”) concentration in the atmosphere. And he proposed that increases in CO_2 levels due to Industrial Revolution emissions of CO_2 might raise the temperature of the Earth’s atmosphere in the future. The debate over the effect of man-made emissions on global warming is still in the headlines today. The debates begun in the late 1800s gave rise to paleoclimatology as scientists look to recreate climate history.

Today scientists have accumulated a body of evidence that climate change is taking place currently. Average temperatures increased in the 1990s, leading many scientists to conclude that the earth is in a period of global warming. The evidence cited for climate change occurring now includes:

- Global sea level rose about 17 centimeters (6.7 inches) in the last century.
- Global surface temperatures have risen by 1.3 degrees Fahrenheit (°F) over the last 100 years. The rate of warming across the globe over the last 50 years (0.24 °F per decade) is almost double the rate of warming over the last 100 years (0.13 °F per decade). Most of the warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years. Worldwide, the last decade has been the warmest on record. The following illustration relates global average temperature and CO_2 concentrations.


Global Average Temperature and Carbon Dioxide Concentrations, 1880-2006

Source: Michael Ernst, Woods Hole Research Center, from **How We Know What We Know About Our Changing Climate**

- Ocean surface temperatures have increased 0.302 °F in the last 40 years
- The Greenland and Antarctic ice sheets have decreased in size. Greenland lost 36 to 60 cubic miles of ice per year between 2002 and 2006, while Antarctica lost about 36 cubic miles of ice between 2002 and 2005
- Glaciers are retreating almost everywhere around the world—including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa

For a comprehensive report from the EPA on current climate change indicators, see http://www.epa.gov/climatechange/indicators/pdfs/ClimateIndicators_full.pdf. And for a slide show on climate change indicators that you can use directly in class, see http://www.epa.gov/climatechange/indicators/pdfs/climate_indicators_slideshow.pdf.

Worldwide researchers are collecting current data on climate change. But if variations in climate have been taking place throughout history, how can scientists "go back in time" and measure climate variations from centuries ago? That is the role of paleoclimatologists.

More on paleoclimatology

Paleoclimatology is the study of past climates. For assessing the history of climate changes we must rely upon "proxy" climate indicators—natural archives that record seasonal or annual climate conditions such as ice cores, tree-ring measurements, laminated sediments, microbial life and corals--combined with the relatively small amount of available historical documentary or instrumental evidence available in prior centuries. Paleoclimatologists gather data from these natural recorders of climate variability, and by analyzing records taken from these and other sources, scientists can extend our understanding of climate far beyond the 100+ year instrumental record.

Listed below are some widely used proxy climate data types:

- **Ice Cores:** Scientists drill into ice sheets and collects long cylinders of ice called cores. These cores contain dust, pollen and gases that can be translated into a history of climate in the region.
- **Tree Rings:** Scientists study the concentric rings that result from the annual growth of trees. The rings have varying widths and density and contain different elemental isotopes depending on climate conditions.
- **Corals:** Much like tree growth, corals exhibit annual variations in the thickness and density of their skeletons. The skeletons are made of calcium carbonate. In addition, the oxygen isotope content of the $CaCO_3$ will vary depending on the temperature of the ocean. Depending on prevailing temperatures, the oxygen in the carbonate may be composed of varying ratios of O-16 and O-18.
- **Fossil Pollen:** The pollen from flowering plants is deposited in the sediment at the bottom of a body of water. From the type of pollen scientists can infer they type of plants living at the time the sediment was created and thereby gain a clue to the climate of that period.
- **Ocean & Lake Sediments:** Scientists take core samples of ocean and lake sediments. In addition to pollen, fossils and chemicals embedded in the sediment are analyzed to determine the climate in the past.
- **Microbial Data:** Foraminifera and diatoms are commonly used microbial climate proxies. Both are aquatic organisms with shells. Foraminifera shells are made up of calcium carbonate ($CaCO_3$) and diatom shells are composed of silicon dioxide (SiO_2). In warmer water environments, the shells will be richer in O-18 and in colder conditions, O-16 will prevail. (See More on ice core chemistry for a detailed explanation of the isotopes of oxygen.)

Paleoclimatologists weave together the data from all of these sources in an attempt to create a history of the Earth’s climate. Proxy records are coordinated with current data and the historical record, usually using computer models. They also use the models to predict future climate.

More on ice core chemistry

Ice cores are considered one of the richest sources of information about climate history. In an ice core you can learn about hundreds of thousands of years of temperature, precipitation, the chemistry and gas composition of the lower atmosphere, volcanic activity, solar variability and a variety of other climate indicators. The fact that this information exists in the same source adds to the value of cores.

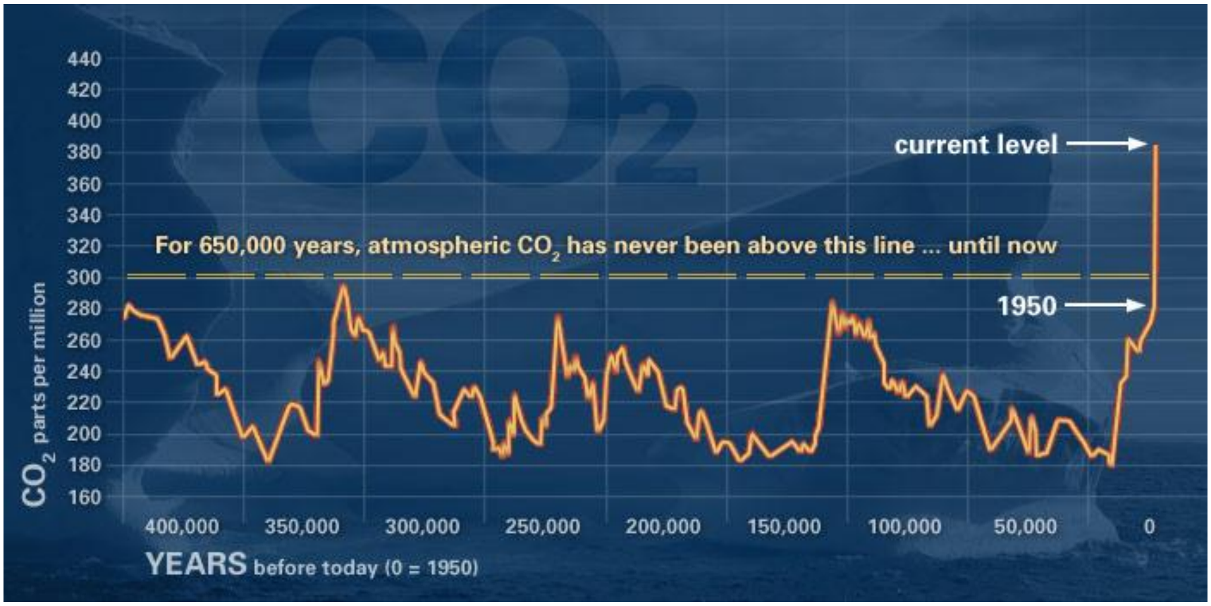
First, the ice itself yields information about the history of the earth's climate. As the article describes, the oxygen making up one component of water exists in two isotopic forms—O-16 and O-18. If your class has not studied isotopes by now you can preview the topic quickly. Tell students that atoms of many of the elements can exist as isotopes. Tell them that all atoms of the same element have the same number of protons—the atomic number of each element is unique. However, the number of neutrons in atoms of the same elements can vary, and that means that two atoms of the same element can have different masses. So in the case of the oxygen isotopes described in the article, each oxygen atom has eight protons. Most oxygen atoms (by far) also have eight neutrons. That's O-16. But a small percentage of oxygen atoms have ten protons. That's O-18, the heavier isotope.

The water making up the ice contains mostly water molecules made up of O-16. But a few are made up of O-18. The O-18 water is heavier (because the O-18 isotope is heavier than the O-16 isotope). Because of this mass difference, the O-16 water has a higher vapor pressure and a slightly lower boiling point than water composed of O-18, and, therefore, it evaporates more easily than O-18 water. So, as past climate temperatures increased, the O-16 molecules evaporated to a greater degree, leaving a slightly increased proportion of O-18 molecules in the water of oceans and lakes. So when chemists examine ice cores and determine the concentration of oxygen isotopes, a higher O-18 to O-16 ratio means that the climate was warmer and a lower ratio means the climate was cooler.

The article looks at this idea from the vantage point of water vapor in the atmosphere. Since O-18 vaporizes at a slightly higher temperature than O-16, it will also condense at that slightly higher temperature, meaning that as the temperature of the atmosphere is cooled O-18 precipitates out first. This increases the O-18 concentration of the liquid water. Consequently, an ice core exhibiting a higher O-18 **:** O-16 ratio would indicate a climate that was cooler.

In addition, the composition of seawater at times past can be derived from the shells of small organisms called foraminifera. These shells are made of Calcium carbonate, $CaCO_3$. If the oxygen in the carbonate is higher in O-18, that would indicate a cooler climate.

The gas composition of the atmosphere can be determined by analysis of very tiny air bubbles that are trapped in the ice. Originally the air had been encased in snow, and over time the snow became ice as the pressure of many years' snow fall packed it down. The air bubbles contain whatever gases were present at the time of the original snowfall. Analysis of the trapped air shows atmospheric conditions at the time. The most common gases—aside from normal nitrogen and oxygen—are carbon dioxide (CO_2) and methane (CH_4), both of which are now known to be greenhouse gases. Higher concentrations of these gases in the air bubbles would suggest that the climate was warmer. The concentration of carbon dioxide in the atmosphere correlates positively with rise and fall of sea levels, suggesting CO_2's role in climate change. Studying the concentration of these gases over time also reveals their influence on natural variations in climate and, therefore, gives clues to the role than man-made CO_2 plays in global warming. The variation of carbon dioxide levels is show in the graph below:



http://climate.nasa.gov/evidence/

Another gas that serves as a climate indicator is hydrogen peroxide, H_2O_2. Hydrogen peroxide is made in the atmosphere by a reaction that requires UV radiation. The fluctuation of H_2O_2 concentration in an ice core gives clues about annual cycles, since UV radiation is much more intense in warmer summer months. Still another gas discovered in the ice is carbon monoxide. In 2010, researchers measured CO concentrations in Antarctic ice cores and were able to infer the rate of burning of organic fuels in the Southern hemisphere.

In addition to gases trapped in ice cores, scientists also study plant pollen found in the cores. Plants spread pollen widely and pollen distribution is well understood. By counting pollen present and by identifying various types, scientist can infer the kinds of plant species present in a given time period and, therefore, the kind of climate—for example, temperature and rainfall—at that time. Also, in some ice core layers volcanic ash will be present. The shape, color and chemistry of the ash gives chemists clues to known volcanic eruptions, thus providing clues to when that layer of ice core was created.

Ice cores are actually long cylinders of ice that has been removed vertically from an ice sheet. Drilling locations are determined using radar to locate safe sites and appropriate depths. Cores are usually three inches in diameter and can be as long as 650 feet. A 250-foot core can be drilled in a day.

Ice caps form from annual layers of snow being pressed together over millions of years. As the snow gets thicker the air is pressed out of it and the flakes are packed into spheres, which is called firn. Firn is further compressed into ice. Often the air that was once in the snow is trapped in the ice.

More on Mt. Kilimanjaro and Lonnie Thompson

Mt. Kilimanjaro is located in northeastern Tanzania, Africa, near its border with Kenya. At 5,895 meters (19,341 ft) Kilimanjaro is the tallest mountain in Africa. Uhuru Peak is the highest summit on the mountain. It has three associated volcanic cones, Kibo, Mawenzi, and Shira. The latter two are extinct, but magma is present about 400 meters below Kibo's crater. The most recent volcanic activity on Kilimanjaro was about 200 years ago. (Map from http://www.state.gov/p/af/ci/tz/index.htm)

The mountain was formed about 750,000 years ago as lava erupted through the land near the Great Rift Valley. The shiny black obsidian stone that marks the mountain was likely formed when Kibo erupted about 650,000 years ago.

Kilimanjaro's glaciers are the result of a unique weather system. The mountain is so big that it produces its own weather pattern. Strong winds from the southeast—trade winds—carry water vapor from the Indian Ocean, and when they reach Kilimanjaro the winds are forced upwards. Rain and snow result. The trade winds bring precipitation to Kilimanjaro between March and May. Winds from the northeast (anti-trade winds) bring precipitation to the north slope between November and February. Most of the rain falls at elevations less than 3000 meters.

So how do the glaciers get there? Meteorologists theorize that normally the very strong northeast winds prevent the moisture-laden southeast winds from making it to the upper elevations of Kilimanjaro. But during the season when the northeast winds subside, the southeast winds rise to the top of the mountain and it is then that snow falls. Over time, glaciers formed and shaped the mountain as they advanced and retreated.

Students might ask how glaciers can exist at a latitude only 4^{o} south of the equator (less than 300 miles). The reason is that the white color of the glacier reflects most of the heat from the sun. However, the black obsidian rock on which the glacier rests does absorb a great deal of heat, melting the glacier from the bottom. This makes the glaciers on Kilimanjaro unstable. Sections break away from the main body of the glacier, exposing more of the black obsidian rock and the process continues. Another factor is the relationship between temperature and elevation. As you increase elevation, the temperature decreases. So while the average temperature in the town of Moshi at the base of the mountain is 70–80 ^{o}F, the average temperature at Uhuru Peak, the top of the mountain, is 0 to -15 ^{o}F, cold enough for ice.

If that is the case, why are there glaciers on Kilimanjaro at all? The answer is that the ice ages being studied by paleoclimatologists like Lonnie Thompson provided cooler conditions under which the glaciers could grow in size. Climatologists believe that in eastern Africa there have been eight of these ice ages, some longer and colder than others.

Approximately 75% of the ice cover on Kilimanjaro was lost between 1912 and 1989. Between 1989 and 2000, one quarter of the remaining ice was lost. The glaciers now measure about 0.8 square mile (2 square kilometers), down from 4.6 square miles (12 square kilometers) in 1912.

Lonnie Thompson began studying ice cores taken from higher elevations around the world in 1974 on a climb to the Quelccaya ice cap in Peru, the world's largest tropical ice cap. Since then he has led 50 climbs in 15 countries to study tropical ice cores and has returned to Quelccaya every two-three years to takes cores and make measurements. Thompson's measurements of the sheets in tropical regions pioneered tropical paleoclimatology.

Photo from
http://www.pnas.org/content/103/31/11437.full

Thompson is a native of West Virginia and a 1970 graduate of Marshall University (best known for the movie about the airplane crash that took the lives of its football team). His degree was in geology. Looking for a way to prepare himself for a coal-related job in West Virginia, Thompson enrolled at Ohio State University in order to study with a well-known coal expert there. However, he was offered a job analyzing ice core samples for Ohio State's then-new polar paleoclimatology department. Instead of studying coal, Thompson switched to the Institute for Polar Studies at Ohio State University where he met John Mercer, a glacial geologist who had been working on an atlas of the world's glaciers, including the one at Quelccaya. This sparked Thompson's interest in tropical ice cores.

The main problem with drilling ice cores in mountainous regions is getting the equipment there. In 1983, Thompson and his party managed to get a lighter solar-powered drill that could be dis-assembled and re-assembled on arrival at Quelccaya where they were able to drill two cores. However, they were unable to keep the cores frozen for the return trip. So they bottled the melted ice samples and took them back to Ohio State to be analyzed. The samples provided Thompson with a record of 1500 years of precipitation in the tropics and proof that the Southern Hemisphere experienced a "Little Ice Age" between 1500 and 1800 CE. Thompson's trip to Kilimanjaro in 2000 yielded evidence that climate change was causing Kilimanjaro's glaciers to melt and put Thompson in the spotlight as a paleoclimatologist.

As the article mentions, there is not universal acceptance of Thompson's global warming explanation for the glaciers' disappearance. In addition to the sublimation explanation offered by Philip Mote in the article, a research team from Austria and the United States took measurement at Kilimanjaro and concluded that the disappearance was due to decreased rainfall over hundreds of years. For more on Mote's views see http://seattletimes.nwsource.com/html/localnews/2003744089_kilimanjaro12m.html.

This disagreement over climate change data can be a useful example for students about how new data has often been open to differing interpretation. These kinds of debates are common in science and, in fact, often lead to further experimentation to test the different ideas.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Phase change**—Creation of glaciers and ice shields involves factors associated with change of phase. This is an opportunity to apply concepts like vapor pressure, vaporization and freezing temperature.
2. **Methods of analysis**—Chemistry is often about analysis. What are the chemical components of this system? Paleoclimatology allows you to discuss with students various types of chemical analysis discussed in the article.
3. **Isotopes**—One of the most important methods of analysis for ice cores is based on the isotopes of oxygen. You can review isotopes or preview them in preparation for discussing this article.
4. **Chemistry and the environment—**Take this opportunity to stress with students that it is often chemists who are analyzing ice core components and other proxy data. Also remind students that many chemicals they might study in the course are important in nature.
5. **Compounds—**A variety of chemical compounds are important in this article—carbon dioxide, methane, oxygen, carbon monoxide, hydrogen peroxide, etc. Their unique properties are what make them important in the context of this article.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"Recent global warming is caused by the sun."** *The sun's energy reaching the earth has been measured for thirty years and it is not increasing. "Satellite observations clearly show the well-known 11-year solar cycle, during which the amount of sunlight reaching the Earth's surface varies by about 0.1 percent. This cycle causes the global temperature to fluctuate up and down by about 0.2 °F, much less than the observed warming of about 1 °F in the past 50 years. More importantly, the solar cycle causes an up-and-down cycle, not an upward trend similar to the trend in the global temperature. The sun's output has not increased over the past three decades." (http://www.pewclimate.org/science-impacts/realities-vs-misconceptions#sun)*
2. **"The last few years have been cooler, so global warming can't be real."** *Some people claim that the planet has entered a cooling phase either since 1998 or since 2005, depending on the data set. However, just because 1998 and 2005 are the two warmest years on record does not mean that a long term warming trend is not continuing. The climate is defined by long-term averages, not the ups and downs that occur every few years. For example, the average temperature for the last five years is higher than for the previous five years, and so on. Even with the variability in global average temperatures, a long-term warming trend remains. The ten warmest years in the 150-year thermometer record have all occurred in the twelve years between 1997 and 2008; thus, none of the previous 15 decades has been as warm on average as the last decade. Even with a short-term pause in warming, the past three years are among the ten hottest years of the past 150. (http://www.pewclimate.org/science-impacts/realities-vs-misconceptions#cooler)*

Anticipating Student Questions (answers to questions students might ask in class)

1. **"How can glaciers exist at a latitude only 4^{o} south of the equator?"** *Despite the fact that Mt. Kilimanjaro is located in the tropics, you need to remember that as you increase elevation, the temperature decreases. So while the average temperature in the town of Moshi at the base of the mountain is 70-80 ^{o}F, the average temperature at Uhuru Peak, the top of the mountain, is 0 to -15 ^{o}F, cold enough for ice.*
2. **How can they tell how old parts of an ice core are?"** *That has been a challenge for paleoclimatologists, who have used multiple methods of dating layers of ice cores. The first 1000 m of a core might represent 10,000 years and the next 1000 meters might represent 100,000 years due to the compacting of the ice over so long a time. Knowing when volcanic activity occurred allows scientists to "mark' a place in the core when the ash from volcanic activity is found. Radioisotope dating has also been used. And scientists know from the ice flow patterns the approximate age of the ice.*

In-class Activities (lesson ideas, including labs & demonstrations)

1. In this activity students use real Antarctic ice core data to learn how scientists learn about climate change from ice cores: http://eesc.columbia.edu/courses/ees/climate/labs/vostok/.
2. Here is another ice core data activity from the TV show NOVA: http://www.pbs.org/wgbh/nova/teachers/activities/3005_vinson.html.
3. This activity allows students to plot CO_2 data from Mauna Loa, Hawaii, and determine rate of increase: http://serc.carleton.edu/introgeo/interactive/examples/co2.html.
4. You can have students analyze simulated ice cores using an adapted version of the lesson plan found at http://www2.umaine.edu/USITASE/teachers/pdf/Ice%20Cores.pdf . Even though the lesson is aimed at grades 3-6, adding variables to the ice can make it appropriate for older students. For example, in addition to varying the layer thickness you could add, for example, dilute sulfate solution to one or more layers to indicate volcanic activity.
5. This data activity correlates sea ice and snow depth: http://tea.armadaproject.org/activity/tea_activity_porter_seaice.html.
6. This lab activity simulates the CO_2 analysis of ice cores: http://www.vcapcd.org/AirTheFilm/pubs/CarbonDioxideinIceCoreSamplesLessonPlan.pdf.
7. You can download a lesson here, http://www.fraserinstitute.org/WorkArea/DownloadAsset.aspx?id=4244, that uses real data to teach students about climate change. This material is very extensive.
8. The Byrd Polar research Center offers a five-module series of classroom activities about ice cores at http://wosu.org/ice-cores/. Each of the five modules—"Climate and Ice," "Recovering Ice Cores," "Calendars in Ice," "Stories in Ice," and "Predictions from the Ice"—have multi-media components and lab activities.

Out-of-class Activities and Projects (student research, class projects)

1. Students could be assigned to read one or more of the entries from this blog, http://kiboice.blogspot.com/, and write a brief summary. The individual summaries could be combined to present a history of this research on Kilimanjaro.
2. Teams of students can be assigned one of the five sectors on this site from the Pew Center on Global Climate Change and prepare a report for the class: http://www.pewclimate.org/climate-techbook.
3. If you wish to assign research on ice core climatology, you can use this site from the Ice Core Paleoclimatology Research Group at Ohio State University as a starting point for assigning the research: http://bprc.osu.edu/Icecore/Abstracts/Publications.html.
4. Students can research timelines based on ice core data and write a report at http://www.pbs.org/wgbh/nova/warnings/stories/.

References (non-Web-based information sources)

Gasse, F. Kilimanjaro's Secrets Revealed. *Science,* October 18, **2002**, *298*, pp 548-549.

Thompson, L. G.; et al. Kilimanjaro Ice Core Records: Evidence of Holocene Climate Change in Tropical Africa. *Science*, October 18, **2002**, *298*, pp 589-593.

Krajick, K. Ice Man: Lonnie Thompson Scales the Peaks for Science, *Science*, October 18, **2002**, *298*, pp 518-522.

Websites for Additional Information (Web-based information sources)

More sites on ice cores

You can view a video on ice cores in Antarctica
here: http://www.youtube.com/watch?v=kdfcNIFEnF8 and
here: http://www.youtube.com/watch?v=zoTXbXsC69k&feature=related and
here: http://www.youtube.com/watch?v=jndT8PphSa8&feature=related.

The U.S. National Ice Core Laboratory, part of the U.S. Geologic Survey, has its own web page with a lot of information, at http://nicl.usgs.gov/. NOTE: see this page of links to other ice core projects: http://nicl.usgs.gov/links.htm>

More sites on paleoclimatology

NOAA has an extensive web site on this topic at http://www.ncdc.noaa.gov/paleo/paleo.html.

NOAA also has a page describing climate proxies at http://www.ncdc.noaa.gov/paleo/primer_proxy.html.

More sites on climate change

NASA has a web page on climate change with data supporting key indications that climate change is taking place: http://climate.nasa.gov/.

The Intergovernmental Panel on Climate Change, the U.S. blue-ribbon panel, has an extensive web site at http://www.ipcc.ch/.

For a comprehensive report from the EPA on current climate change indicators, see http://www.epa.gov/climatechange/indicators/pdfs/ClimateIndicators_full.pdf.

For a slide show on climate change indicators you can use in class see http://www.epa.gov/climatechange/indicators/pdfs/climate_indicators_slideshow.pdf.

In 2008, the National Academies of Science issued this report on climate change: http://dels-old.nas.edu/dels/rpt_briefs/climate_change_2008_final.pdf.

An extensive web site on climate change can be found at http://www.global-climate-change.org.uk/.

More sites on the contributions of Svante Arrhenius to global warming theory

For a biography of Arrhenius from the Nobel Prize site see http://nobelprize.org/nobel_prizes/chemistry/laureates/1903/arrhenius-bio.html.

To read Arrhenius' 1896 paper in which he first advanced the question of whether the presence of carbon dioxide in the atmosphere contributed to the warming of the atmosphere see http://www.rsc.org/images/Arrhenius1896_tcm18-173546.pdf.

More sites on Mt. Kilimanjaro

To view a video on Mt. Kilimanjaro go to http://wn.com/Mount_Kilimanjaro.

For the U.S. Department of State "Background Notes" on Tanzania, the country in which Kilimanjaro is located, see http://www.state.gov/r/pa/ei/bgn/2843.htm.

More sites on Lonnie Thompson

For a complete biography of Thompson see http://www.pnas.org/content/103/31/11437.full.

To see a National Geographic interview with Thompson go to http://www.nationalgeographic.com/adventure/0408/q_n_a.html.

For a five part interview with Thompson see http://wn.com/lonnie_thompson.

The web site for Thompson's home base, the Byrd Polar Research Center is http://bprc.osu.edu/.