CHEMMATTERS

April 2012 Teacher's Guide

Table of Contents

About the Guide

Teacher's Guide editors William Bleam, Donald McKinney, Ronald Tempest, and Erica K. Jacobsen created the Teacher's Guide article material. E-mail: bbleam@verizon.net

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

Articles from past issues of *ChemMatters* can be accessed from a CD that is available from the American Chemical Society for $30. The CD contains all *ChemMatters* issues from February 1983 to April 2008.

The *ChemMatters CD* includes *an* Index that covers all issues from February 1983 to April 2008.

The *ChemMatters* CD can be purchased by calling 1-800-227-5558.

Purchase information can be found online at www.acs.org/chemmatters

Student Questions (from the articles)

Artistic Chemistry: A Beautiful Collaboration

1. What are the steps typically involved in making pottery?
2. How is making Raku pottery different from making traditional pottery?
3. What happens in a redox reaction?
4. When Raku pottery is made using redox, what is reduced? What is oxidized?
5. Why are the glazes used in Raku selected to contain both metals and oxygen?
6. How were stained glass windows from the past, such as those found in cathedrals, constructed?
7. Describe the steps the stained glass artist in the article uses to construct a stained glass piece of art.
8. What is used as a cleaning agent in stained glass construction? Why is it needed?
9. What is solder? How is it used in stained glass?

Microbes and Molasses: A Successful Partnership

1. What is the name of the toxic chemical that seeped into the groundwater in Germantown, Wisconsin, and what was it used for there?
2. What is bioremediation?
3. What is the difference between aerobic and anaerobic bacteria?
4. How is dry cleaning different from the clothes washing we are used to?
5. Why is perchloroethylene a good solvent for use in dry cleaning?
6. What is the legal limit for the amount of perchloroethylene in drinking water?
7. What is the role of the molasses in the Washington Square bioremediation?
8. Why are hydrogen atoms important in this bioremediation?

From Fish Tank to Fuel Tank

1. What is meant by the term “hydrocarbon”?
2. What is the primary material from which gasoline and diesel fuel is currently produced?
3. Using words, “write” the equation that describes the burning of a hydrocarbon.
4. Why do growers of algae remove the nutrient nitrogen in the culture tanks?
5. Define the term “biofuel”.
6. Speaking in general terms, what are the two most common biofuels?
7. For the two categories of biofuel in question 6, what are the general methods for producing each?
8. Describe the chemical steps needed to produce ethanol fuel from plant carbohydrates.
9. Energy-wise, how does the biofuel ethanol compare to the biofuel biodiesel?
10. Why can biodiesel be used to power a large jet airliner but ethanol cannot?
11. What two advantages favor algae rather than corn or soybeans as the source of biodiesel production?

Recycling Aluminum: A Way of Life or a Lifestyle?

1. List the three steps involved in recycling aluminum in Dharavi.
2. What fuel does Muktar use in his furnace?
3. How is he able to obtain the high temperatures needed to melt the aluminum?
4. What makes aluminum recycling profitable?
5. Describe the three-step Bayer process, by which aluminum oxide is purified from bauxite.
6. What happens next to the aluminum oxide?
7. Describe the two advantages aluminum has for recycling.
8. What frequently happens to used plastics, and why?
9. Why isn't it convenient to recycle green glass?
10. Why don't we recycle iron, like we do aluminum?

Tasers

1. How did the name "Taser" come about?
2. How does a Taser work?
3. What are nerve cells called?
4. There is a space between neurons called a synaptic cleft. Name the chemicals that neurons release into this space.
5. What causes neurotransmitters to be released into the synaptic cleft?
6. How does a shock from a Taser affect the release of neurotransmitters?
7. How can a Taser deliver 1200 volts without killing a person?

Answers to Student Questions (from the articles)

Artistic Chemistry: A Beautiful Collaboration

1. **What are the steps typically involved in making pottery?**
   Traditional pottery consists of sculpting pots, decorating them with a glaze, and heating them to high temperatures in a kiln so they can harden before letting them cool down outside.
2. **How is making Raku pottery different from making traditional pottery?**
   Sculpting a Raku pottery piece and glazing it is similar to traditional pottery, but the heating and cooling steps are done quickly instead of gradually.
3. **What happens in a redox reaction?**
   A redox reaction involves both oxidation (loss of electrons) and reduction (gain of electrons).
4. **When Raku pottery is made using redox, what is reduced? What is oxidized?**
   The metals in the glaze components are reduced, while the carbon or carbon monoxide coming from the combustion is oxidized.
5. **Why are the glazes used in Raku selected to contain both metals and oxygen?**
   The glaze compounds contain oxygen, which is used as a source of oxygen for combustion when there is no supply of atmospheric oxygen. The metals form metallic streaks on the pottery as the metallic ions are reduced into elemental metal.
6. **How were stained glass windows from the past, such as those found in cathedrals, constructed?**
   Artists connected large window pieces with a reinforcing material called a lead came, which was soldered at the junctions between the window pieces.
7. **Describe the steps the stained glass artist in the article uses to construct a stained glass piece of art.**
   After cutting colored glass into the desired shapes, she edge-wraps each piece of glass with a narrow strip of copper foil. Then, she applies cleaning agent to the copper. She melts solder onto the seams between the glass and finally applies a liquid patina.
8. **What is used as a cleaning agent in stained glass construction? Why is it needed?**
   Hydrochloric acid, which is formed by exposing zinc chloride to moisture and heat, is used as a cleaning agent. It removes any oxides that are present on the surface of the copper foil, so that only copper is exposed to the solder.
9. **What is solder? How is it used in stained glass?**
   Solder is a mixture of metals with low melting points. It adheres to the copper foil on the edges of the glass pieces and is used to hold them together.

Microbes and Molasses: A Successful Partnership

1. **What is the name of the toxic chemical that seeped into the groundwater in Germantown, Wisconsin, and what was it used for there?**
   The chemical is called perchloroethylene, and it was being used as a solvent in a dry cleaning establishment.
2. **What is bioremediation?**
   In general bioremediation is the use of living organisms to fix environmental problems. In the case described in the article, anaerobic bacteria are used to break down the

perchloroethylene, which is harmful to the environment, into ethylene gas, which is not harmful.

3. **What is the difference between aerobic and anaerobic bacteria?**
   Aerobic bacteria require oxygen in order to produce energy needed to live. Anaerobic bacteria can produce energy using chemicals other than oxygen as their energy producer.
4. **How is dry cleaning different from the clothes washing we are used to?**
   Clothes that are dry cleaned are washed in an organic solvent, like perchloroethylene, that dissolves grease and stains. No water is involved.
5. **Why is perchloroethylene a good solvent for use in dry cleaning?**
   It is able to dissolve most organic stains like greases, oils and fats. Since it is non-flammable, it is safe to use. However, because it is a volatile liquid, it escapes into the air easily, and inhalation can cause a variety of health effects, including damage to the liver and central nervous system. The compound has been shown to cause cancer in rats and its carcinogenic effect in humans is being evaluated.
6. **What is the legal limit for the amount of perchloroethylene in drinking water?**
   Most states limit the concentration of perchloroethylene to 5 parts per billion. In the Washington Square case the concentration was 2,000 parts per billion.
7. **What is the role of molasses in the Washington Square bioremediation?**
   The molasses serves as a food source for the anaerobic bacteria and a source of hydrogen atoms. In the series of reactions that takes place, the perchloroethylene takes the place of oxygen in the oxidation reaction. So, instead of a reaction like
   glucose + oxygen → CO_2 + water,
   the anaerobic reaction would be
   glucose (from molasses) + perchloroethylene → CO_2 + ethylene + acid.
8. **Why are hydrogen atoms important in this bioremediation?**
   In the oxidation-reduction reactions that decompose the perchloroethylene, chlorine atoms are removed from the perchloroethylene and replaced by hydrogen atoms.

From Fish Tank to Fuel Tank

1. **What is meant by the term "hydrocarbon"?**
   A hydrocarbon is a molecule composed of only hydrogen and carbon atoms.
2. **What is the primary material from which gasoline and diesel fuel is currently produced?**
   Gasoline and diesel fuel are produced from petroleum.
3. **Using words, "write" the equation that describes the burning of a hydrocarbon.**
   Hydrocarbons combine with or react with oxygen to produce carbon dioxide, water vapor and the release of energy.
4. **Why do growers of algae remove the nutrient nitrogen in the culture tanks?**
   When nitrogen is removed from the culture tanks, the algae start dividing (multiply) and producing more oil inside the algae cells.
5. **Define the term "biofuel".**
   A biofuel is a fuel that comes from biological material produced by crops or plants.
6. **Speaking in general terms, what are the two most common biofuels?**
   The two most common biofuels are methyl esters and alcohol.
7. **For the two categories of biofuel in question 6, what are the general methods for producing each?**
   Methyl esters are produced from the triacylglyerols of plants. Alcohol is produced by the fermentation of the carbohydrates extracted from plant material.

8. **Describe the chemical steps needed to produce ethanol fuel from plant carbohydrates.**
   The carbohydrates of plants are converted into alcohol by a two-step process. First, larger molecules such as cellulose and starch are broken down in to smaller glucose molecules by hydrolysis (decomposition by reaction with water). Next, the smaller sugar molecules are converted into alcohol (ethanol) and carbon dioxide by microorganisms such as bacteria and yeast in a process known as fermentation.
9. **Energy-wise, how does the biofuel ethanol compare to the biofuel biodiesel?**
   Ethanol releases less energy per unit mass than biodiesel.
10. **Why can biodiesel be used to power a large jet airliner but ethanol cannot?**
    Biodiesel contains more energy per unit mass of fuel compared with ethanol, enough to power a jet airliner for the maximum volume of fuel that can be carried by the plane—which would not be possible for an equal volume of ethanol.
11. **What two advantages favor algae rather than corn or soybeans as the source of biodiesel production?**
    The oil extracted from algae has a higher energy content than ethanol which is produced from carbohydrates of corn and soybeans. Second, using corn or soybeans to produce biofuel competes with the use of corn and soybeans as food, raising the price of both food sources which would not be the case for algae.

Recycling Aluminum: A Way of Life or a Lifestyle?

1. **List the three steps involved in recycling aluminum in Dharavi.**
   The three steps of recycling aluminum are:
   a. *Collect old soda and beer cans and anything aluminum,*
   b. *Soak the cans in acid to remove the designs and printed brands on the outside,*
   c. *Crush the cans and melt them in a furnace to produce blocks of aluminum.*
2. **What fuel does Muktar use in his furnace?**
   Muktar uses coal as the fuel in his furnace.
3. **How is he able to obtain the high temperatures needed to melt the aluminum?**
   His furnace, nothing more than a hold in the ground, has a hole at the bottom of the pit. It is a vent, connected by a pipe to the outside air. This vent allows air to enter the bottom of the furnace. The oxygen of the air reacts with the hot coal (combustion) to produce the high temperatures needed.
4. **What makes aluminum recycling profitable?**
   Aluminum recycling is profitable because
   a. *it is expensive to extract aluminum from aluminum ore,*
   b. *extracting it pollutes the environment, and*
   c. *the process of extracting consumes a significant amount of energy.*
5. **Describe the three-step Bayer process, by which aluminum oxide is purified from bauxite.**
   The three-step Bayer process of extracting alumina from bauxite follows:
   a. *Dissolve the bauxite in sodium hydroxide at high temperature and pressure to produce sodium aluminate,*
   b. *Separate the aluminum hydroxide precipitate, produced from the sodium aluminate, from the rest of the impurities by precipitation of the hydroxide,*
   c. *Heat the resulting aluminum hydroxide at a temperature of 980 °C to remove water to produce aluminum oxide, alumina.*
6. **What happens next to the aluminum oxide?**

The aluminum oxide (alumina) is then smelted. The process is based on electrolysis. This requires that the alumina be dissolved in molten cryolite. The mixture is then electrolyzed into aluminum at the cathode and oxygen, subsequently changed to carbon dioxide, at the anode.

7. **Describe the two advantages aluminum has for recycling.**
   The two advantages aluminum has for recycling are:
   a. *Since aluminum is used in large quantities in the U.S., we can save a lot of space in landfills by recycling it rather than "throwing it away", and*
   b. *Since aluminum requires a lot of energy to produce from its raw materials, it is much cheaper to recycle aluminum than to produce it from its ore.*
8. **What frequently happens to used plastics, and why?**
   Used plastic "… is often burned or buried simply because it is not cost-effective to recycle it." The raw materials used to make new plastic frequently cost less than it would cost to recycle the used plastic.
9. **Why isn't it convenient to recycle green glass?**
   Glass is recycled by color. Some colors of glass are not as widely used in the U.S. as in other countries. Green colored glass, for example, is imported to the U.S. via beer and wine bottles, but it is not used as much in the U.S. Thus green glass has almost no market in the U.S. and is not as profitable for recycling.
10. **Why don't we recycle iron, like we do aluminum?**
    We don't recycle iron because it corrodes and forms iron oxide. It is very difficult to remove the oxygen from iron oxide to convert it back to iron. Aluminum on the other hand, does not corrode.

Tasers

1. **How did the name "Taser" come about?**
   The Taser's inventor, John Cover, was a fan of the early 1900s Tom Swift stories. In one of the stories Swift invented an electric rifle. When Cover developed his Taser in the late 1960's he named it for the first letters in ***T****homas* ***A****.* ***S****wift's* ***E****lectric* ***R****ifle.*
2. **How does a Taser work?**
   The device propels two barbed electrodes that are attached to the Taser unit itself by insulated wires. When the electrodes attach themselves to a person, either in the person's clothing or skin, the Taser delivers a shock to the person that interferes with muscle control and incapacitates them for a short period of time.
3. **What are nerve cells called?**
   These specialized cells are called neurons.
4. **There is a space between neurons called a synaptic cleft. Name the chemicals that neurons release into this space.**
   These chemicals are called neurotransmitters. The chemical acetylcholine is an example of a neurotransmitter.
5. **What causes neurotransmitters to be released into the synaptic cleft?**
   When a neuron is stimulated by an electric impulse from a neighboring neuron, the permeability of its cell wall changes; this allows sodium ions to pass through the cell wall. The increase in sodium ion concentration inside the cell causes it to release a neurotransmitter into the next synaptic cleft. This process continues along the cells in the nervous system
6. **How does a shock from a Taser affect the release of neurotransmitters?**

The electric pulses from a Taser cause neurons to release excess neurotransmitters, which, in turn, signal the receiving muscle cells to contract temporarily, thus immobilizing the shocked person for a brief time.

7. **How can a Taser deliver 1200 volts without killing a person?**
   The article says that volts measure the potential difference between the two Taser electrodes. That is actually the electric ***force*** *that pushes electrons through the person. But the article also says that it is the* ***number*** *of electrons flowing through the person that is harmful. This property of electricity is measured in amperes, and Tasers deliver between 0.002 and 0.02 amperes of current, not enough to kill a person.*

ChemMatters Puzzle: Chemical Word Search

Here is an intriguing variation of a WORD SEARCH puzzle with a chemical theme.

In the 11x12 grid, 23 terms (shown below) are hidden. All are words/units important to the chemist, and six are some famous scientists' last names. The terms will be found in the grid going in a straight line… leftward, rightward, up, down, or in any diagonal direction.

The kicker is that in the list of terms, the first letter is left out. You'll want to supply it, as the whole word appears in the grid. The grid coordinates are given to help you discuss with others or check your answers.

One more thing: With all the first letters in place, they will generate when read top to bottom a statement. This might help you work backwards to obtain a first letter, if needed. The statement is an unorthodox **answe**r to a **question** many a chem student has been asked over the years;

"What is the formula of the chemical whose boiling and melting point are 100 degrees apart?"

The terms

column 1
__att
__cid
__orr
__nzyme
__edox
__teel

column 2
_ _erric
_ _xide
_ _adon
_ _etal
_ _rea
_ _ewis

column 3
__lkali
__sotope
__TP
__aber
_ __ somer
__oule

column 4
__elvin
__iquid
__ole
__obel
__ octane

The word search grid

	a	b	c	d	e	f	g	h	i	j	k
1	L	E	E	T	S	I	W	E	L	A	L
2	E	B	U	T	E	D	A	S	L	G	I
3	N	E	P	B	N	M	T	A	E	Q	Q
4	A	Q	L	I	Z	P	T	L	C	N	U
5	T	J	T	O	Y	E	E	K	U	I	I
6	C	I	S	O	M	E	R	A	R	V	D
7	O	S	A	F	E	V	S	L	E	L	O
8	X	O	D	E	R	C	Z	I	A	E	H
9	I	T	O	R	R	A	D	O	N	K	A
10	D	O	H	R	T	A	D	P	A	Y	B
11	E	P	F	I	S	O	J	O	U	L	E
12	B	E	T	C	L	E	B	O	N	E	R

Answers to the *ChemMatters* Puzzle

The 23 terms in order are as follows. The first letter's grid coordinates are given, to help you find the term's position in the grid. Remember, some terms will appear along a diagonal starting with that position, as well as the more common left, right, up, or down.

Watt (James)	1g
Acid	3h
Torr	9b
Enzyme	2e
Redox	8e
Steel	1e
Ferric	7d
Oxide	7a
Radon	9e
Metal	6e
Urea	5i
Lewis (G.N.)	1i
Alkali	3h
Isotope	6b
STP	1e and/or 2h
Haber (Fritz)	8k
Isomer	6b
Joule (James)	11g
Kelvin (Willam Thomson, Lord Kelvin)	9j
Liquid	lk
Mole	6e
Nobel (Alfred)	12i
Octane	7a

The statement is: "Water's formula is H I J K L M N O" (H to O !!)

NSES Correlation

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Artistic Chemistry**	**Microbes and Molasses**	**From Fish Tank to Fuel Tank**	**Recycling Aluminum**	**Tasers**
Physical Science Standard B: of the structure and properties of matter.	✓	✓	✓	✓	
Physical Science Standard B: of chemical reactions.	✓	✓	✓	✓	
Physical Science Standard C: of matter, energy, and organization in living systems.		✓	✓		
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: of environmental quality		✓	✓	✓	
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.		✓	✓	✓	✓

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.

Artistic Chemistry: A Beautiful Collaboration

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. Raku potters know in advance how the pottery will look after firing.
		2. Reduction occurs when a metallic ion gains one or more electrons.
		3. Some of the oxygen required for combustion comes from compounds in the glaze.
		4. When electrons are lost by one element, they are gained by another element.
		5. Stained glass windows in old cathedrals and churches are connected by cames made of copper.
		6. The stained glass artist brushes the copper foil with hydrochloric acid.
		7. Copper chloride ($CuCl_2$) dissolves in water.
		8. The solder used in making stained glass has a high melting point.

Microbes and Molasses: A Successful Partnership

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. Molasses is made from sugar cane.
		2. In some bioremediation projects, anaerobic bacteria break down certain compounds to produce energy.
		3. PCE, or perchloroethylene, is a liquid used to dry clean clothes because it dissolves grease.
		4. PCE is flammable and has a low density.
		5. The PCE concentration found in drinking water under the mall described in the article was 10 times higher than allowed by the Safe Drinking Water Act.
		6. Soil from the contaminated site described in the article is still there.
		7. A year after bioremediation began, the concentrations of PCE were too small to be detected.
		8. Replacing the chlorine atoms in PCE with hydrogen atoms produces a harmless compound (ethylene).
		9. Oil spills have been cleaned up with bioremediation.
		10. Bioremediation has not been approved for cleanup on military bases.

From Fish Tank to Fuel Tank

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 green slime (algae) in a fish tank feels oily.
		2. When hydrocarbon molecules, including diesel fuel, burn, carbon dioxide is produced.
		3. Oil from algae has molecules with long hydrocarbon chains similar to the hydrocarbons in diesel fuel.
		4. Burning biodiesel has an advantage over burning diesel fuel because algae takes in CO_2 when it grows, which compensates for the CO_2 produced when biodiesel burns.
		5. Algae would produce less oil per acre than soybeans or corn crops.
		6. One kind of biofuel is made by converting carbohydrate molecules into alcohol molecules.
		7. More energy is produced by burning one gram of biofuel from corn than one gram of biofuel from algae.
		8. Algae can be grown year-round.
		9. Ethanol can be used in jet fuel.
		10. One of the biggest challenges in using algae for biodiesel is separating algae from water.

Recycling Aluminum: A Way of Life or a Lifestyle?

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. Thousands of people living in India make a living by recycling.
		2. Sodium hydroxide is used to remove the designs from old aluminum cans before they are crushed and melted.
		3. Aluminum’s melting point is above 2000 °C.
		4. Electrolysis can be performed on solids, liquids, and gases.
		5. Sodium hydroxide is added to bauxite ore in the first stage of the Bayer process to extract aluminum from its ore.
		6. Producing aluminum ingots from bauxite ore requires much more energy than producing aluminum ingots from recycled cans.
		7. It is economically advantageous to recycle almost all materials, including plastic and green glass.
		8. Iron is easier to recycle than aluminum.
		9. Workers at recycling plants in India are provided with safety equipment.

Tasers

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 term "Taser" is related to the term "laser" because the last four letters in each name stand for the same words.
		2. Tasers fire darts with electrodes that penetrate skin or clothing.
		3. Tasers deliver electricity to a person's body for 10 seconds.
		4. Tasers make the neurons in a person's body touch.
		5. An electric signal can change the permeability of a cell membrane.
		6. Your body requires ions to transmit nerve impulses.
		7. Tasers cause all muscles in a person's body to contract at the same time.
		8. The potential difference between the electrodes in a Taser is 120 volts.

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

Note: Several of the articles involve redox chemistry. You might consider asking students this question if they read all of the articles:

What chemical reaction is common to the articles about producing Raku pottery, treating PCE to create ethylene, and extracting aluminum from its ore?

Artistic Chemistry: A Beautiful Collaboration

Directions**:** As you read the article, look for examples of physical and chemical changes as well as the elements involved when making Raku pottery and stained glass. Complete the chart below.

	Raku Pottery	**Stained Glass**
Physical change(s)		
Chemical change(s)		
Elements involved		

Microbes and Molasses: A Successful Partnership

Directions: As you read, complete the chart below to describe how the events described in the article occurred, and the chemistry involved in each event.

	How did it happen?	**Where's the chemistry?**
Toxic pollution		
Bioremediation		

From Fish Tank to Fuel Tank

Directions: As you read, compare and describe the advantages and disadvantages of using algae with using other crops to produce biofuels.

	Advantages	**Disadvantages**
Algae		
Other crops (specify each crop)		

Recycling Aluminum: A Way of Life of a Lifestyle?

Directions: As you read, compare the steps used in producing aluminum for beverage cans.

Steps	Is this step done by recyclers?	Physical or Chemical Change?	What happens in this step?
Aluminum refining			
Smelting			
Ingot casting			
Shredding and decoating			

Tasers

Directions: As you read, complete the chart below telling why each chemical is included in the article.

Chemical	Why is the chemical mentioned in the article?	What does the chemical do related to Tasers?
Nitrogen		
Acetylcholine		
Sodium ions		
Potassium ions		
Calcium ions		

Artistic Chemistry: A Beautiful Collaboration

Background Information (teacher information)

More on Raku pottery

As the Herlocker article states, the form of Raku pottery dates back to the mid-16th century in connection with Sen no Rikyu, a Japanese tea master and former Zen monk. Further history of Raku is described at http://www.mpsaz.org/mesa/staff/ljphelps/Raku_history/:

> The term *Raku* is derived from the site where clay was dug in Kyoto in the late 16th century and is found in the Kanji character meaning “enjoyment” or “ease.” For 15 generations it has been the title and seal used by a lineage of potters whose work formed the central tradition in Japan. This lineage believes that “Raku” refers to the potters who use the technique, not the technique itself.
>
> In the 16th century, the first of these potters, Chōjirō is said to have come under the patronage of the Japanese tea master Sen-No-Rikyu. According to legend, in 1598, the ruler Hideyoshi, after Chōjirō's death in 1592, bestowed upon his adopted son, Jokei, a golden seal with the written symbol "Raku." Both the name and the ceramic style have been passed down through the family to the present. After the publication of a manual in the 18th century, Raku ware was also made by numerous workshops in and around Kyoto: by amateur potter tea practitioners and by professional and amateur potters around Japan.
>
> The use of a reduction chamber at the end of the Raku firing was introduced by the American potter Paul Soldner in the 1960s to compensate for the difference in atmosphere between wood-fired Japanese Raku kilns and gas-fired American kilns. Typically, pieces removed from the hot kiln are placed in masses of combustible material (e.g., straw, sawdust, or newspaper) to provide a reducing atmosphere for the glaze and to stain the exposed body surface with carbon.
>
> In a craft conference in Kyoto in 1979, a heated debate sprang up between Western Raku artists Paul Soldner and Rick Hirsh and the youngest in the dynastic Raku succession, Kichiemon, (Part of the fourteenth generation of the “Raku” family of potters.) concerning the right to use the title “Raku”. The Japanese artists maintain that any work by other craftsmen should hold their own name, (i.e. Soldner-ware, Hirsh-ware), as that was how “Raku” was intended.

The *ChemMatters* article focuses on work done by an artist in a studio, but the history of working with clay and its potential practical uses are much wider and could be subjects for further discussion in the classroom. The textbook *Art in Chemistry; Chemistry in Art* describes:

> Ceramics is the art of molding and firing or heating clay to a high temperature, resulting in hard, permanent objects. The Greeks, who played an important role in the development of ceramics, called their works *keramos*, from Keramikos, a section of Athens, Greece, where most of the ceramic artists worked and sold their art. Our word ceramics

> comes from this Greek word. Today, the word ceramics indicates something much broader than just the art of pottery. It includes the making of such products as bricks, kitchen sinks, bathtubs, floor tiles, and walls. Ceramics are used in many industries to make components that resist high temperatures. Ceramics are a part of our everyday lives. (p 154)

The basic materials for both traditional pottery and Raku pottery methods are the same—clay to form the pottery shape itself, glaze to create a surface with the desired properties, and a kiln to expose the clay and glaze to heat. The makeup of clay itself is described in *Art in Chemistry; Chemistry in Art*:

> There are many types of clay. Natural clay is earth or soil generally found beneath topsoil. Found almost everywhere, natural clay is formed when rocks—mostly feldspar, which is a mixture of potassium oxide (K_2O), aluminum oxide (Al_2O_3), and silicon dioxide[*] ($K_2O \cdot Al_2O_3 \cdot 6H_2O$)—breaks down under the action of weather and through chemical reactions. Variations in this empirical formula, and the addition of other substances such as Na_2O (sodium oxide), change the clay's color and texture. Natural clay becomes plastic and cohesive when moist because it consists of platelets made of silicon (Si), oxygen (O), hydrogen (H), and aluminum (Al) atoms, bonded into an arrangement having the empirical formula $Al_2Si_2O_5(OH)_4$, which slide over one another when water is present. Natural clay becomes hard when exposed to heat, either from the sun or when baked or fired in a kiln. Ordinary baked clay pottery has a rough, porous surface. To make it more attractive, waterproof, and useful, it is given a smooth, shiny surface by a process called glazing. (p 153)

[*Instructors should note that the textbook itself includes an error for the formula of silicon dioxide in the quote above and one should always carefully read over any material used in the classroom. The textbook is still cited here, as it contains many useful art-related activities.]

This property of plasticity allows one to mold and shape clay into the desired shapes. If natural clay is air-dried, it is called green ware. At this stage, it is quite fragile. The changes that clay undergoes when heated is described in the *J. Chem. Educ.* article "The Joy of Color in Ceramic Glazes with the Help of Redox Chemistry" (**2001**, *78* (10), pp 1298–1304):

> By heating in a kiln, the chemically bound water is removed (at about 350 ºC). Continued heating leads to the quartz inversion at 573 ºC, when the alpha quartz converts to the beta form. Continued heating leads to vitrification, a process in which partial fusion occurs within the clay, causing some shrinkage and hardening. The cooling process must then be allowed adequate time so that the transition at 573 ºC can be passed without structural failure. The cooled clay object is then called bisque ware, ready for the application of a glaze.
>
> Today potters usually prefer gas-fired or electric kilns, both of which can be easily regulated. Temperature control and regulation is important for a firing process to succeed. It is still possible to operate a kiln based on observing the color within and by using ceramic pyrometric cones. These are small ceramic cones formulated to slowly melt and deform in relation to the temperature and time of heating. Observing these cones through a spy hole permits the potter to evaluate the heating cycle.

> Most kiln firings are done with an oxidizing environment, meaning with a generous oxygen supply. Gas- and oil-fired kilns provide a reducing environment when their oxygen supply is reduced below optimal. The kiln then contains hot carbon particles and significant amounts of carbon monoxide, both excellent reducing environments. (pp 1298, 1300)

The same article also discusses glazes:

> The very first glazes were probably formed when alkaline ashes from the wood fire were carried into the kiln and served as a flux to lower the melting point of the clay surface and form a thin glass layer. Eventually potters learned to formulate a "glaze" that could be applied to the bisque ware and then fired to form a new surface that had a better appearance and could be readily cleaned after using with food or beverages.
>
> The first glazes had colors due to metals such as iron or copper that were present in the clay or glaze materials. Iron, the second most abundant metal in the earth's crust, is present in many clays and glaze ingredients. Thus, early pottery most often had earth tones. (pp 1300, 1302)

Different compounds can be added to glazes to produce a range of colors. The final color depends on many variables, such as the temperature used for firing, and whether an oxidative or reducing environment is used in the kiln. For example, the addition of iron to a glaze can result in colors such as yellow, tan, brown, reddish brown, black, gray, and green.

The processes of creating traditional pottery and Raku pottery differ once the firing process is reached. Raku pottery undergoes a much shorter, faster firing. Even within the "genre" of Raku pottery, there are differences. The processes and these differences are described at http://www.ceramicstoday.com/articles/branfman_Raku.htm:

> To briefly describe the Raku process we must understand that most all other types of pottery are loaded into a cold kiln where the firing proceeds slowly until the desired temperature is reached. This firing cycle may take anywhere from 8-24 hours or even longer. When the kiln has reached temperature (which is generally determined through the use of pyrometric cones), it is shut off and allowed to cool enough to be able to remove the ware using bare, or lightly gloved hands. The cooling cycle may last from 12-24 hours or longer. The ware is considered finished when it is taken from the kiln. In Raku, the pieces may be loaded into a cold kiln but are often preheated and loaded into a hot kiln. The firing proceeds at a rapid pace with the wares reaching temperature in as short a cycle as 15-20 minutes (though Raku firings can last up to several hours depending on the individual pieces and their firing requirements). Glaze maturity is judged by the trained eye without the use of cones or measuring devices. When the firing is determined to be completed the wares are immediately removed from the kiln. Since at this point the glaze is molten, tongs or other lifting devices are used.
>
> This is the stage in the process where traditional and contemporary Raku differ in technique and treatment. In our western version the wares are now treated to a "post firing reduction" phase. The wares are put into a container with combustible material such as sawdust, or leaves and

allowed to smoke for a predetermined length of time. The carbonaceous atmosphere reacts and affects the glazes and clay and imparts unique effects and surfaces to the wares. Some of these effects are metallic and crackled glazes surfaces and black unglazed clay. When the wares have cooled, they are washed with an abrasive cleaner to remove all residue of soot and ash.

More on stained glass

The Herlocker article describes an artist that creates stained glass artwork by piecing together small bits of colored glass using a copper foil and solder technique. Stained glass has come to generically mean artwork or decorative windows that are constructed from pieces of colored glass. There are various ways of attaching the pieces, from using supporting channels called lead cames and solder, as illustrated in the article in figure 1, to using copper foil and solder as shown in other photographs in the article. In addition to lead cames, zinc and brass cames can be used. Both zinc and brass are less malleable than lead and can provide support for the glass pieces without stretching or sagging. The term “stained” refers to a particular process of coloring glass.

A “Glass Dictionary” at the Corning Museum of Glass website states that staining is: “In glass working, the process of coloring the surface of glass by the application of silver sulfide or silver chloride, which is then fired at a relatively low temperature. The silver imparts a yellow, brownish yellow, or ruby-colored stain, which can be painted, engraved, or etched” (http://www.cmog.org/research/glass-dictionary/s - staining). The dictionary also states that the term “stained glass” is somewhat inaccurate because stained glass artists also use glass colored by methods other than staining (http://www.cmog.org/research/glass-dictionary/s - stained-glass). One of these methods is to use powdered metal oxides to color glass. This method is illustrated in a figure and caption from a past *ChemMatters* article. The article also presents a full discussion of the composition of glass and its manufacture; rather than reproducing that here, readers are encouraged to see that reference (Baxter, R. Glass: An Amorphous Solid. *ChemMatters* **1998**, *16* (3), pp 10–11).

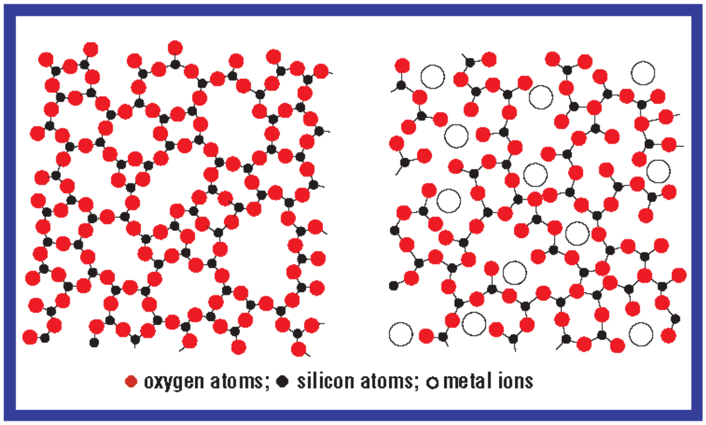


ILLUSTRATION BY ACS GRAPHICS

“Pure SiO_2 glass has no orderly arrangement of atoms in rows and columns of military precision (left). When metal ions are added (right), they fit into the glass matrix and form a non-directional bond to oxygen atoms. This weakens the matrix and, in turn, decreases the viscosity and the melting temperature range. The new glass is now easier to work.” (p 11)

The October 2006 *ChemMatters* Teacher’s Guide (pp 23–24) (http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/CTP_005456) contains a list of some of the common oxides and the color of glass associated with each.

Oxide	**Color**
Iron	green, brown
Manganese	amethyst
Cobalt	deep blue
Gold	red
Antimony	white
Copper	light blue
Lead/antimony	yellow

When connecting the pieces of cut glass together after they have had copper foil applied to their edges, the article discusses the use of a cleaning agent on the copper. The purpose of using the agent is to remove oxides present on the surface of the copper to promote better bonding when the edges are soldered together. The compounds used to do this are called "flux" (from Latin *fluxus*, meaning "flow"). The website document "How to Solder Like a Pro" (http://www.inlandcraft.com/howto/pdf/htsold.pdf) describes flux:

> Flux is a chemical compound that is used to promote the bonding of metals by removing the oxide residue simultaneously with the soldering process. Most metals left exposed to the air around us react with the air to form residue on the surface of the metal. The process is oxidation and the residues are oxides. Each mix of metals being joined has a specific flux that best promotes the bonding process. In stained glass, the metals being joined are primarily copper to tin/lead solder and lead, brass or zinc to tin/lead solder. The best fluxes do three things: They remove all the residue that has formed on the surface of the metals you are going to solder. They prevent oxides from forming while you are soldering. Any post-soldering residue they leave is noncorrosive and easily cleaned off.

The flux described in the Herlocker article is hydrochloric acid, which is formed by exposing zinc chloride to moisture and heat. After the copper foil pieces are joined using solder, the flux needs to be cleaned away using a flux remover. If the flux is allowed to remain on the stained glass piece, the flux can continue to react and can oxidize the materials, creating undesired effects.

Solder is used to bond the copper foil pieces. A past *ChemMatters* article describes solder (Brownlee, C. Bling Zinger: The Lead Content of Jewelry. *ChemMatters*, **2006**, *24* (2), pp 11–14): "Solder is an alloy of metals that when heated, melts (alloying metals can lower melting points) and flows into the joints where two edges of metal come together. Upon cooling, the solder hardens to produce the seal for the joint." (p 12) The use of solder in a stained glass creation has several benefits (http://www.inlandcraft.com/howto/pdf/htsold.pdf): "Solders are easy to use and relatively inexpensive. Low energy is required to solder. Properly soldered joints are highly reliable. Solder joints are easy to rework or repair. Experienced craft persons can exercise a high degree of control over the soldering process. Solder joints age very well. They can last for years, decades and centuries." Various solders are used in stained glass. The Herlocker article mentions the use of tin–lead 50/50 solder. Two other tin–lead solders are also used in stained glass, 60/40 and 63/37. The first number represents the percentage of tin in the solder and the second number the percentage of lead present. Each mixture has a different melting point and a different range that it can be worked, that is, a temperature range after it melts but before it solidifies. The choice of solder for a project depends on the effect one wishes to achieve. The properties of the three solder mixtures are described at the "How to Solder Like a Pro" website (http://www.inlandcraft.com/howto/pdf/htsold.pdf):

> **60/40 Solder:** Composed of 60% tin and 40% lead, this solder melts at 374 ºF, but doesn't become completely solid until it cools to 361 ºF. This means it has a "pasty range" or "working range" of 13 degrees. This solder is your best choice for copper foil work. The liquid temperature and narrow "pasty range" make it easy to form and maintain consistent high, rounded, beaded seams. Because of its relatively low melting point, "60/40" solder is easy to rework to maintain a smooth finish solder bead.
>
> **50/50 Solder:** This is composed of 50% tin and 50% lead. It is liquid at 421 ºF, solid at 361 ºF and has a pasty range of 60 degrees. This solder will produce a much "flatter" bead than 60/40. Because of its higher melting point, 50/50 solder is often used on the back (or inside) of a stained glass project to protect against "melt through" when soldering the front. Because it spreads and flattens out, 50/50 solder is often used when soldering lead came joints.
>
> **63/37 Solder:** This solder is 63% tin and 37% lead. It becomes liquid at 361 ºF, and solid at 361 ºF, with a pasty or working range of 0 degrees. This solder is called a eutectic alloy which means at 361 ºF, you can go instantly from solid to liquid to solid just by applying or removing the heat source. You will often find "63/37" solder referred to as decorative or quick set solder. It is primarily used to create dimensional effects in the solder itself and can be "pulled" and manipulated to produce a variety of textures and designs. 63/37 solder also makes an excellent solder to bead up the outside rim of copper foiled pieces.

The use of solder can also be connected to its past use in the making of tin cans. In the 1800s cans were formed by soldering a piece of tin-coated iron into a cylinder. The *ChemMatters* article (Brownlee, C. Bling Zinger: The Lead Content of Jewelry. *ChemMatters*, **2006**, *24* (2), pp 11–14) states “The solder used at the time was about 90% lead and would not flow easily, making it difficult to obtain a perfect seal” (p 12). This difficulty in sealing the can led to problems with potential lead poisoning. One example that occurred during a ship’s expedition in 1845 is described in the *ChemMatters* article.

The history of the use of glass can also be incorporated into a discussion of the Herlocker article. The ChemSource 3.0 module “Materials Science: Ceramics and Glasses” briefly mentions its history:

> Glass has also been known for many centuries, as evidenced by the glass beads found in archaeological digs. The Romans discovered glass blowing—probably around 50 B.C. In the Middle Ages, Italian and French artisans forced blown glass bubbles into various shapes and flattened them into sheets. From that discovery came a variety of bottles, jars, glasses, and stained glass windows. Experimentation with recipes and production processes also arose. Within decades of the beginning of the industrial revolution, glass products became established as economically important construction materials. Glass windows became commonplace, rather than a decoration found only in cathedrals. (p 18)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Phases of matter—**Both Raku pottery and stained glass have potential for connection with a discussion of phases of matter and how they can change, such as clay and its plasticity, glaze components before and after firing, and solder used in stained glass.
2. **Oxides—**Both the topics of Raku pottery and stained glass can be linked to oxides. In Raku pottery, oxides are specifically added; glazes contain metal oxide compounds, which serve as a source of oxygen during part of the firing process. In stained glass, oxides are not desired, as it interferes with effective soldering of the copper foil.
3. **Redox reactions—**The article shows potential redox reactions occurring when a copper glaze is used in Raku pottery. Further discussion of redox reactions could include balancing additional examples of reactions. For more on redox reactions, see the Background Information section of either the bioremediation article or the aluminum recycling article in this *Teacher's Guide*.
4. **Combustion—**Combustion reactions could be discussed in the context of the combustion that occurs during the Raku firing process. Students could also compare any differences between gas-fired and coal-fired kilns, such as atmospheric environment and products.
5. **Chemistry and color—**The use of various metal oxide compounds and how they are used to color glass used in stained glass projects could be discussed.
6. **Alloys—**Stained glass solder can be connected with the concept of alloys and how the properties of an alloy, including a lower melting point than its components, can be tuned to specifically desired properties.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"An artist is always able to plan what his or her piece of pottery will look like."** *The appearance of a Raku pottery piece is at least somewhat uncertain until the very end of the process. Certain materials can be used to contribute a particular type of color and appearance to the final glaze, but the exact results cannot be predicted. As the article states, "…every piece is a surprise!"*

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

1. **"Is the look of a Raku pottery piece totally random?"** *All Raku pottery is known for its unpredictable nature. However, chances of getting certain colors can be enhanced by selecting the right glaze metals, although kiln conditions can make even the most carefully selected metals take on unexpected hues.*
2. **"How does solder hold things together?"** *The website http://eecs.oregonstate.edu/education/docs/tutorials/rogersolder.pdf states: "Solder provides a metal solvent action between the solder and the metal(s) being joined. This 'solution' of*

metal in the solder results in an intermediate alloy being formed. This provides metal … continuity.”

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

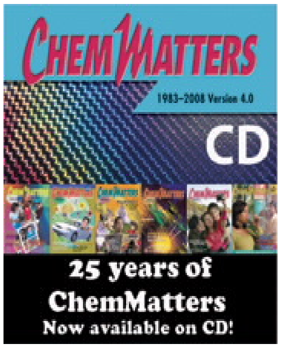
1. High school students have been able to experience making Raku pottery through school art or chemistry courses. For three such schools, see http://www.johnstoninsider.com/stories/05.2011/0405/Johnston_High_School_wins_RISCA_grant,_hosts_artist-in-residence.html, http://www.westerville.k12.oh.us/school_NewsArticle.aspx?artID=2473&schoolID=29, and http://blog.ashbury.ca/?p=5928.
2. Several clay and glaze activities are part of the textbook *Art in Chemistry; Chemistry in Art* (see section 4), available online at http://www.scribd.com/doc/39098643/Greenberg-Art-in-Chemistry-Chemistry-in-Art-2e-Colors-IIP-2008.
3. A short discussion of metals and alloys is accompanied by an experiment to turn pennies into “silver” and “gold”; students form the alloy brass. (http://www.pbs.org/safarchive/4_class/44_guides/guide_804/4484_glory.html)
4. A brief activity uses glue, food coloring, and dish detergent to connect to the idea of stained glass. (http://chicagoacs.net/ChmShort/CS05.html, partway down page)

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

1. As the article states, students may wish to become familiar with Raku pottery or stained glass by volunteering at an art studio or by taking classes locally.
2. Students could visit a local glassblowing studio to investigate how certain colors of glass are produced.

References (non-Web-based information sources)

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 Web site 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 <u>and</u> Teacher’s Guides are available on the 25-year CD for all past issues, up to 2008.)

Some of the more recent articles (2002 forward) referenced below may also be available online at the URL listed above. Simply click on the “Past Issues and Teacher’s Guides” button at the right. If the article is available online, that will be noted.

The *ChemMatters* article “Glass: An Amorphous Solid” provides excellent background in the chemical composition of glass, its manufacture, and how glass can be decolorized or colored. (Baxter, R. *ChemMatters*, **1998**, *16* (3), pp 10–11)

The *ChemMatters* article “Bling Zinger: The Lead Content of Jewelry” discusses past uses of lead, including in solder. (Brownlee, C. *ChemMatters*, **2006**, *24* (2), pp 11–14)

The history of glass and the beautiful and useful products it can make are described and colorfully shown in the article “Glass—Sand + Imagination.” (Kolb, K. E.; Kolb, D. K. *J. Chem. Educ.* **2000**, *77* (7), pp 812–816, see http://www.chihuly.com/Data/Sites/2/PageDocuments/JCE_77_p812.pdf)

A SourceBook module discusses ceramics and glass in the context of materials science. Becker, W.; Epperson, B. E.; Lamb, W. “Materials Science: Ceramics & Glasses.” In *SourceBook*, Version 3.0, edited by Orna, M. V.; Smith, P. J. V. ChemSource, Inc.: New Rochelle, NY, 2010.

The *Journal of Chemical Education* article “Art as an Avenue to Science Literacy: Teaching Nanotechnology through Stained Glass” (Duncan, K. A. et al. *J. Chem. Educ.* **2010**, *87* (10), pp 1031–1038) links art to nanotechnology through a series of activities related to stained glass. Students create “stained glass” using overhead transparencies, simulated liquid leading, and nanoparticle solutions. The abstract is available at http://pubs.acs.org/doi/abs/10.1021/ed1000922, with the full article available to subscribers.

Art in Chemistry; Chemistry in Art is an extensive textbook that brings together chemistry and art concepts. It contains sections on color, paint, clay, sculpture, jewelry, 2-D and 3-D art, and photography. Each section contains several activities related to the topic. (Greenberg, B. R.; Patterson, D., *Art in Chemistry; Chemistry in Art*, 2nd ed. 2008, Libraries Unlimited/Teacher Ideas Press, Westport, CT. Available online at http://www.scribd.com/doc/39098643/Greenberg-Art-in-Chemistry-Chemistry-in-Art-2e-Colors-IIP-2008)

An older *Journal of Chemical Education* article, “Raku: A Redox Experiment in Glass,” discusses Raku and contains an experiment where students glaze crucible lids (which does require a muffle furnace). (Cichowski, R. S. *J. Chem. Educ.* **1975**, *52* (9), pp 616–618) The abstract is available at http://pubs.acs.org/doi/abs/10.1021/ed052p616, with the full article available to subscribers.

The article “The Joy of Color in Ceramic Glazes with the Help of Redox Chemistry” describes the different effects that can be achieved in the look of pottery, with many photos. (Denio, A. A. *J. Chem. Educ.* **2001**, *78* (10), pp 1298–1304) The abstract is available at http://pubs.acs.org/doi/abs/10.1021/ed078p1298, with the full article available to subscribers.

Web Sites for Additional Information (Web-based information sources)

More sites on Raku

The three-page document “Using the Raku Glazing Process to Show Oxidation-Reduction in Chemistry” summarizes the role of oxidation-reduction when firing Raku pottery. It includes an interesting legend related to its discovery. (http://www.asminternational.org/content/docs/Raku.pdf)

Raku pottery is described, along with the history of its Japanese roots and Western-based Raku techniques. (http://www.mpsaz.org/mesa/staff/ljphelps/Raku_history/)

A series of photographs illustrates the use of Raku by an artist who sculpts beads, earrings, and pendants from clay. (http://www.justerica.com/pages/What-is-Raku%3F.html)
The site http://www.ceramicstoday.com/articles/branfman_Raku.htm answers 21 frequently asked questions about Raku.

Categories of ingredients used in glazes are described, along with a list of chemicals commonly used for each. (http://www.duncanshearer.co.nz/glaze/glazechemistry.html)

The history of Raku and the steps taken to create Raku pottery are shown in a series of photographs and accompanying text. (http://pottery.about.com/od/firingthekiln/ss/Raku_firing.htm)

A YouTube video shows firing of several Raku pottery pieces, including blowing on a piece to achieve a crackle finish. Photos of the finished pieces are shown at the end of the video. (http://www.youtube.com/watch?v=xrBoqrQ_L4Y)

More sites on stained glass

The Stained Glass Association of America website contains an extensive discussion of the history of stained glass. (http://stainedglass.org/?page_id=169)

An article includes sections on the history of stained glass, the chemistry of glass, and how it is colored. (http://www.guardian.co.uk/science/blog/2010/oct/29/science-magic-stained-glass)

A slide show with accompanying text discusses how craftsmen in the Middle Ages were able to produce beautiful stained glass windows, with photos of stained glass examples. (http://www.pbs.org/wgbh/nova/ancient/science-stained-glass.html)

The different compounds used to color glass are discussed at http://geology.com/articles/color-in-glass.shtml.

The history of stained glass, what it is, and how it is made are shared at the site http://www.visual-arts-cork.com/stained-glass-art.htm.

A blog post at *C&E News* highlights stained glass made by a chemist that shows the structure of theobromine, a compound present in chocolate. (http://cenblog.org/newscripts/2010/07/more-chemical-artwork/)

A YouTube video shows the application of copper foil to the edges of a stained glass piece and soldering it to an adjoining piece. (http://www.youtube.com/watch?v=E7NBCNY1Tck)

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

A lesson plan requires students to research the artists and methods used to make two Japanese tea bowls (including a Raku piece) and then make tea bowls of their own. It relates to visual arts and reading/writing/communicating standards rather than science, but does teach observation skills. (http://creativity.denverartmuseum.org/wp-content/uploads/2011/03/TeaBowls_Sec.pdf)

A seven-day project “Let’s Get Fired Up with Raku” is briefly described here: http://www.kinf.org/projects/AR/345ARletsgetfiredupwithRaku.pdf.

Microbes and Molasses: A Successful Partnership

Background Information (teacher information)

More on bioremediation

Your students will likely understand that many substances with toxic properties have been introduced into local environments as a result of human activity, like the dry cleaning establishments described in the article. And many of these contaminants are deposited in soil or groundwater where they may continue to pose a health or safety risk to living organisms—including people. Cleaning up contaminated sites like Washington Square using traditional remediation methods are complicated and expensive.

In the example in the article, perchloroethylene (PCE) that was spilled at the dry cleaning site migrated into the water table below the site. PCE is a dense liquid (in bioremediation terms it is known as a dense non-aqueous phase liquid or DNAPL) and therefore sinks into soil easily. It should be noted that only a small percent of PCE released into the environment makes its way into groundwater. Because PCE is so volatile, most of it is vaporized into the atmosphere. However, as PCE percolates downward and reaches the water table it can remain there for long periods of time, since it is only slightly soluble in water and, therefore, not easily dispersed. This persistence in the environment means that it is a long-term problem and one that the EPA and other agencies were eager to remediate.

In the Washington Square Mall example and other sites contaminated by perchloroethylene, bioremediation returns the environment to its original condition or close to it. So the end product of the degradation of perchloroethylene, ethylene, is a rather harmless gas. The process may be employed in order to attack specific contaminants, such as chlorinated solvents like perchloroethylene, that are able to be degraded by bacteria, or a more general approach may be taken, such as in oil spills that are broken down using multiple techniques including the addition of fertilizer to facilitate the decomposition of crude oil by bacteria. The remediation may be done *in situ*—at the contaminated site—or *ex situ*—moving the contamination to another location for treatment. The article describes both types. Topsoil from the Washington Square site was excavated and treated at a landfill (*ex situ*), while the local groundwater was treated using the injected molasses-bacteria method *in situ*. In the case of pollution from chlorinated volatile organic compounds at or near ground level, *ex situ* remediation is often used to prevent the pollutant from evaporating into the atmosphere and causing further pollution. In this case the surface soil or water is contained, removed to another site and treated. *Ex-situ* remediation is much more difficult for pollutants that migrate well below the soil surface. That is the advantage of the kind of *in-situ* bioremediation (ISB) described in the article.

Beginning in the 1970s scientists turned to bioremediation as a strategy for such cleanups. Bioremediation is defined as any process that uses microorganisms like bacteria or their enzymes to alter or improve a local environment by breaking down toxic chemical substances into substances that are less toxic or even beneficial. Bioremediation can be used when three ingredients are present: a contaminant (PCE), an electron acceptor (the PCE), and microorganisms (anaerobic bacteria) whose enzymes can degrade the contaminant. In bioremediation these microbes utilize chemical contaminants in the soil as an energy source, and through oxidation-reduction reactions, metabolize the contaminant into useable energy. By-products (metabolites) released back into the environment are typically in a less toxic form than the parent contaminants.

This description of bioremediation from the Interstate Technology and Regulatory Council, a consortium of more than 40 states, in their report “A Systematic Approach to In Situ Bioremediation in Groundwater” sums it up well:

> Bioremediation is the application of biological treatment to the cleanup of contaminants of concern. It requires the control and manipulation of microbial processes in surface reactors or in the subsurface for *in situ* treatment.
>
> Basically, bioremediation melds an understanding of microbiology, chemistry, hydrogeology, and engineering into a cohesive strategy for controlled microbial degradation of specific classes of organic compounds and, in certain instances, inorganic compounds as well. This assemblage of science and engineering requires a rigorous degree of data evaluation to determine the effect and efficiency of bioremediation.
>
> ISB (in situ bioremediation) entails the creation of subsurface environmental conditions conducive to the degradation of chemicals (i.e., the target chemical) via microbial catalyzed biochemical reactions. This is a technical way of saying that certain microbes can degrade specific chemicals in the subsurface by optimizing their environmental conditions (which causes them to grow and reproduce) (Cookson, 1995). In turn, the microbes produce enzymes that are utilized to derive energy and that are instrumental in the degradation of target chemicals. In order to accomplish this chain of events, several crucial aspects must converge, according to the National Research Council (NRC, 1993):
>
> - the type of microorganisms,
> - the type of contaminant, and
> - the geological conditions at the site.
>
> Once converged, such conditions accelerate microbial activity that, in turn, cause target chemical “biological” destruction. This bioremediation solution yields an elegant and cost-effective way to attack chemicals in the environment using naturally occurring microbes.
> (http://www.itrcweb.org/Documents/ISB-8.pdf)

Here is a simple overview of how the process works for perchloroethylene. PCE is an ethylene molecule, C_2H_4, in which all four of the hydrogen atoms are replaced by chlorine atoms resulting in a formula of C_2Cl_4 (see “More on perchloroethylene” for details). In the language of bioremediation PCE is referred to as a chlorinated volatile organic compound (CVOC). During bioremediation of PCE, each chlorine atom is replaced by a hydrogen atom in a series of redox reactions. PCE is converted to trichloroethylene (C_2HCl_3), which is converted to dichloroethylene ($C_2H_2Cl_2$). Replacing one more chlorine atom with a hydrogen atom results in vinyl chloride (C_2H_3Cl), and this is then converted to ethylene (C_2H_4). The entire process is called reductive dechlorination.

In the case discussed in the article, the microorganisms are bacteria already living in the soil at the contaminated Washington Square site. Several types of bacteria can be used but *Dehalococcoides* bacterium is the only anaerobic bacterium which can completely degrade each of the compounds from PCE to ethylene (for more detail on this strain see http://microbewiki.kenyon.edu/index.php/Dehalococcoides_ethenogenes). In some situations the local bacteria, including *Dehalococcoides,* are able to convert contaminants into non-hazardous compounds without any help. This is called “*natural attenuation*” or intrinsic bioremediation. In the Washington Square case, however, the bacteria required an additional nutrient—the molasses—in order to clean the site. This is referred to as “bio-stimulation.” In some other cases the naturally occurring bacteria are not able to degrade contaminants so the site is “bio-augmented” by adding more appropriate bacteria. Bacteria or other organisms used in this way are called bioremediators.

A simple example of bioremediation that your students are likely to be familiar with is composting, which is simply a microorganism-aided process that improves soil structure, increases organic matter and provides added nutrients. The microorganisms active in composting are called decomposers. Chemical decomposers include bacteria and fungi. All of the bacteria involved in the composting process are aerobic bacteria—they oxidize organic composting material, especially the carbon portion. A wide range of bacteria function over varying temperatures in the compost pile. Since oxidation is an exothermic process, the temperature of the compost pile increases. As the temperature increases different types of bacteria do their work. Psychrophilic bacteria function between 55 ^oF and 70 ^oF (10–20 ^oC). At 70 ^oF mesophilic bacteria take over and continue until the pile temperature reaches 100 ^oF (38 ^oC), at which point thermophilic bacteria rapidly decompose organic matter until the pile temperature reaches 160 ^oF (71 ^oC). As the organic matter is depleted the temperature drops and mesophilic again become active. This composting example illustrates how multiple varieties of microorganisms can work together naturally during the bioremediation process. It also suggests why the use of bacteria for remediation is desirable—there are billions of them in the soil naturally. In fact, one spoonful of good soil contains between 100 million and 1 billion bacteria, each one less than I micrometer wide.

The primary differences between composting and the bioremediation in the article are that the article deals with remediation of contaminated ground water and that the bacteria involved in the article are anaerobic rather than aerobic.

In addition to the Washington Square case, bioremediation is used to clean up contamination resulting from oil spills, sewage discharge, nitrogen compounds, pesticides and herbicides, metals and radionuclides. The United States Geological Survey gives some other examples of bioremediation here: http://water.usgs.gov/wid/html/bioremed.html.

It might also be interesting for you to note to students that bioremediation requires an interdisciplinary approach that blends knowledge of microbiology, chemistry, hydro-geology, and engineering to be effective.

More on perchloroethylene

The U.S. Environmental Protection Agency offers this description of perchloroethylene:

> Perchloroethylene (also called PERC) is a colorless, nonflammable liquid. It does not occur naturally but is produced in large amounts (310 million pounds in 1991) by three companies in the United States. U.S. demand for PERC declined about 35% from 1989 to 1991, and is likely to continue to fall. Solvent recycling and reduced demand for chlorofluorocarbons are major reasons for this trend. The largest U.S. user of PERC is the dry cleaning industry. It accounts for 80% to 85% of all dry cleaning fluid used. Textile mills, chlorofluorocarbon

> producers, vapor degreasing and metal cleaning operations, and makers of rubber coatings also use PERC. It can be added to aerosol formulations, solvent soaps, printing inks, adhesives, sealants, polishes, lubricants, and silicones. Typewriter correction fluid and shoe polish are among the consumer products that can contain PERC.

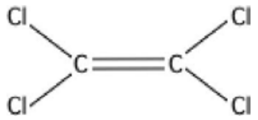
Other names for the compound include perc, PCE, tetrachloroethylene and ethylene tetrachloride.

Important properties of the compound include:

Molecular Weight: 165.85 g/mol
Color: Clear, Colorless.
Phase at room temp. Liquid
Boiling Point: 121.3 °C (250.3 °F)
Melting Point: -22.3 °C (-8.1 °F)
Critical Temperature: 347.1 °C (656.8 °F)
Specific Gravity: 1.6227 (Water = 1)
Vapor Pressure: 1.7 kPa (@ 20 °C)
Vapor Density: 5.7 (Air = 1)
Odor Threshold: 5 - 50 ppm
Flammability: Not flammable
Solubility: Miscible with alcohol, ether, chloroform, benzene, hexane. It dissolves in most of the fixed and volatile oils. Solubility in water: 0.015 g/100 mL @ 25 °C. It slowly decomposes in water to yield trichloroacetic and hydrochloric acids.

Perchloroethylene has several uses. About 60% of all production is used for dry cleaning. It is also used in vapor degreasing and metal cleaning operations; in aerosol formulations; as a carrier for rubber coatings, solvent soaps, printing inks, adhesives, sealants, polishes, lubricants, and silicones; and as a solvent in various consumer products, such as typewriter correction fluid and shoe polishes. Until the early 1990s it was used in the production of chlorofluorocarbons. Because of its toxic properties, production of PCE has been decreasing steadily since 1978.

Its chemical structure is diagrammed at right. The compound is derived from ethylene, which is an unsaturated organic hydrocarbon. Such compounds have at least one double covalent bond in the structure. Ethylene is the simplest alkene with a simple formula of C_2H_4. The general formula for the series of ethylene hydrocarbons is $C_nH_{2n.}$ Ethylene reacts with chlorine to produce perchloroethylene, C_2Cl_4.



PCE is a significant groundwater and air pollutant. In humans it causes toxic effects in the liver, kidney and nervous system. The major contamination route is via breathing contaminated air.

More on oxidation-reduction

You may or may not have covered oxidation and reduction when you have your students read this article. Most texts have several chapters on this topic, but a simple review of major ideas is in order. Generally oxidation-reduction reactions are any chemical reactions in which atoms change their oxidation number. The reactions may be simple ones, like $C + O_2 \rightarrow CO_2$, in which oxygen is oxidized and carbon is reduced. Or the reactions may be more complex like the oxidation of glucose in the body via a series of electron transfers to produce carbon dioxide and water.

Oxidation is defined as loss of electrons and reduction is defined as gain of electrons. If an atom loses electrons its oxidation state (or oxidation number) becomes more positive and if an atom takes on electrons its oxidation state (number) becomes more negative. Oxidation and reduction always occur together in order to conserve electrons. We say that the overall oxidation-reduction reaction occurs in two half reactions, one describing the oxidation part of the overall reaction and the other describing reduction.

In an oxidation-reduction reaction the substance that removes electrons from other substances is said to be the oxidizing agent. And because it accepts electrons, it is reduced. Of course, the reverse is also true. The substance from which electrons are removed is called the reducing agent, and it is itself oxidized.

As mentioned above, many important biological reactions are oxidation-reduction (redox) reactions. The example used above is the oxidation of glucose in cellular respiration. Photosynthesis is the reduction of carbon dioxide into sugars.

In the bioremediation of PCE in the article, PCE accepts electrons and is, therefore, reduced. The glucose in the molasses that is added to the site is oxidized to produce the hydrogen needed to replace the chlorine atoms in the PCE and its resulting daughter molecules. The anaerobic bacteria release enzymes that cause glucose and PCE bonds to break, enabling the reactions to occur. Table 1 in the article describes the multiple step process.

More on dry cleaning

When a fabric is dry-cleaned, solvents other than water are used in place of water**.** Using something other than water to remove stains from cloth is not new. The ancient Romans used ammonia derived from urine to launder woolen clothes. They also used a mixture including Fuller's earth to remove oil stains. Fuller's earth is an absorbent form of aluminum silicate, and it got its name because a craftsman called a fuller applied the clay-like substance to wool in order to remove stains.

Beginning in the mid-1800s, modern dry cleaners used flammable petroleum-based solvents like kerosene or gasoline. In 1928, these were replaced briefly by Stoddard solvent, a mixture of aliphatic, alicyclic and aromatic hydrocarbons that was less volatile and less flammable than its predecessors. By the mid-1930's chlorinated solvents were adopted as dry-cleaning agents because they cleaned better and were even less flammable. Perchloroethylene was soon the solvent of choice because it is non-flammable and because it cleans fabrics well without damaging the cloth, has no residual odor, is chemically stable during use in dry-cleaning and is easily removed from clothes. As noted above, however, PCE is thought to be carcinogenic and has significant adverse health effects. Other solvents that are being used for dry-cleaning include dipropylene, glycol tertiary-butyl ether, liquid silicone, and liquid carbon dioxide.

In the early days of dry-cleaning the process was done in factories. Clothes were collected at neighborhood shops and sent to local factories for processing. Many of these factories used vented processing drums, meaning that large quantities of PCE were vented into the atmosphere, similar to the way modern clothes dryers are vented to the outside, causing the problem described in the article. In modern machines, the dry-cleaning process is closed; that is, any vaporized PCE is condensed and returned to the system.

Current dry-cleaning machines look a lot like a combination of a washer and dryer. The washing chamber is actually a chamber-within-a-chamber. PCE fills the outer chamber and surrounds the basket containing clothes. During the washing cycle the clothes basket is filled about one-third full with PCE. A wash cycle lasts for 8-15 minutes. When the wash cycle is complete the PCE is filtered, distilled and recycled for the next wash cycle. The clothes go through a rinse cycle with fresh PCE. The solvent is extracted from the clothes by spinning the basket (like the spin cycle in a conventional washer). The clothes are then dried by passing warm air through the basket to remove any remaining PCE, which is recycled for future use. The use of a closed solvent-recovery system greatly reduces the amount of PCE escaping into the atmosphere.

As noted above, PCE is classified as harmful to humans and must, therefore, be treated as hazardous waste. The state of California declared it a toxic chemical, and it will be illegal in the state by 2023. Prior to its being recognized as hazardous, workers in dry-cleaning shops often vented the vapors into the air or discharged any spilled PCE into the ground. Dry-cleaning workers are at most risk for exposure, and standards have been set to protect them. For the U.S. Department of Labor OSHA standards, see http://www.osha.gov/dsg/guidance/perc.html.

More on soil bacteria (aerobic/anaerobic)

The example of bioremediation described in this article depends on bacteria in the soil to clean up the site. In general, a teaspoon of soil contains between 100 million and 1 billion individual bacteria. A ton of microscopic bacteria may be active per acre and there may be over one million species of bacteria present. Bacteria are tiny, one-celled organisms about 4/100,000 of an inch (0.00004 in.) wide (about 1 *µ*m, they range from 0.2 to 2 *µ*m) and somewhat longer in length (1–10 *µ*m). Bacteria are similar in size to clay soil particles (<2 *µ*m) to silt soil particles (2–50 *µ*m). The small bacteria size enables these microbes to grow and adapt to changing environmental conditions more rapidly than larger, more complex microorganisms. Bacteria that need oxygen for their survival are called aerobic bacteria, and bacteria that do not require oxygen for survival are called anaerobic bacteria. Anaerobic bacteria cannot bear oxygen and may die if kept in an oxygenated environment.

The report from the Interstate Technology and Regulatory Council describes the use of microbes to remediate toxic substances in the environment:

> The basic premise of bioremediation is to accelerate microbial activity using nutrients (i.e., phosphorus, nitrogen) and substrate (i.e., food) to create conditions conducive to biodegradation of a target chemical or contaminant. This is not new. Sanitary engineers understood the implications of bioremediation as early as the turn of the 20th century when the first vestiges of the common sewage treatment plant were first recognized, applied, and utilized for treatment of raw human excrement (i.e., sewage). These engineers recognized that controlled aeration of sewage would cause a decrease in odor and offensiveness. They also observed that the effluent from such treatment could be easily settled (i.e., clarified) and then discharged to a watercourse without the detrimental effects of the original raw sewage. This was one of the first applications of engineered bioremediation systems to enhance environmental conditions.

What these engineers discovered was that microbial conditions could be optimized through an engineered approach that resulted in biodegradation of the obnoxious organic matter and also produced positive impacts on the overall environment. But to accomplish such an effect, a more precise understanding of microbes and microbial processes needed to be developed.

Microorganisms (or microbes) are microscopic organisms that have a natural capability to degrade or destroy a wide range of organic and inorganic chemicals. Such microbes and the processes by which such degradation occurs are important to understand.

Microbes can use a variety of organic chemicals for their own growth and propagation. These organic chemicals may serve various functions but primarily may be used as either a carbon source for growth or as a source of electrons for energy.

Microbes extract energy via catalyzing energy–yielding biochemical reactions, thus enzymes produced by the microbe can cleave chemical bonds and assist in a transfer of electrons from a chemical compound.

These types of reactions are termed oxidation-reduction reactions, where the organic chemical (contaminant) is oxidized (i.e., electrons are lost) and another chemical (or acceptor) gains electrons (or is reduced). For instance, many organic compounds can serve as an electron donor, such as benzene; while oxygen can serve as an electron acceptor. This is the classic aerobic respiration process. Here microbes "eat" benzene and "breathe" oxygen.
$C_6H_6 + 0_2 \rightarrow CO_2 + H_2O$

In this instance within the subsurface saturated zone, one would expect to observe a decrease in oxygen and the organic contaminant with a simultaneous increase in carbon dioxide. Such resultant biochemical signatures can be monitored.

On the other end of the spectrum are the anaerobic processes, those processes that function without oxygen. In such processes, nitrate, sulfate, iron, manganese, hydrogen, or carbon dioxide can function as an electron acceptor during the anaerobic degradation of organic contaminants.

Such anaerobic respiration processes utilize inorganic chemicals as an electron acceptor. For example, anaerobic hydrogen-oxidizing bacteria can degrade (or dechlorinate) PCE to TCE with the release of a proton (H+) and chloride ion:
$PCE + H_2 \rightarrow TCE + H^+ + Cl^-$
(http://www.itrcweb.org/Documents/ISB-8.pdf)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Biochemistry/biotechnology—**Since this article is about the use of bacteria to remediate groundwater, it shows how chemistry is involved in these living processes. And since bioremediation is an application of biological processes to a complex problem, it also falls within the category of biotechnology.
2. **Organic Chemistry—**Much of the chemistry involved in this article—from the molasses injected into the site, to the enzymes involved, to PCE itself—is organic chemistry. It is not essential that students understand organic structures or notation to appreciate the article.
3. **Oxidation-Reduction—**The basic mechanism by which bacteria eliminate PCE from the groundwater in this article is by a series of oxidation-reduction reactions, which are outlined in the article.
4. **Environmental chemistry—**Many students become interested in chemistry (and other sciences) as a result of their interest in the environment. This article can be used to promote interest in chemistry by describing its role in helping to solve a serious

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"I thought bacteria cause disease. Why don't bacteria in the soil make people sick?"** *This is a common misconception. Harmful bacteria like* Salmonella typhi, which causes typhoid fever, or Yersinia pestis, the cause of the plague, are important historically. Today we know that familiar bacteria like Chlamydia*, Escherichia coli or Streptococcus can cause serious problems in humans. However, we should also understand that there are hundreds of beneficial bacteria like the more than 25 species that can live in our mouths or the bacteria that aid in digestion, right down to the bacteria that help coffee beans take on their taste. In a gram of soil there are* 10^8 *bacteria and among these are more than 100,000 species, most of them beneficial.*

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

1. **"Do bacteria really 'eat' PCE?"** *The term "eat" simply refers to the way in which we take in nutrients that we need for building our bodies and for energy. And since oxygen is readily available, oxygen is the oxidizing agent for our food. A bacterium, however, does not have a mouth. It takes in nutrients by sending enzymes into the surrounding medium. The enzymes break down available molecules (in the article, glucose from molasses). The bacterium then takes these smaller molecules into its single cell by osmosis or active transport. In the case described in the article, there is no oxygen available underground so the bacteria use the PCE as the oxidizing agent. So although the bacteria do metabolize the molasses using PCE instead of oxygen, they don't "eat" the molecules the way we think about the eating process.*
2. **"The article says that the PCE that contaminated the Washington Square site was gone after 18 months. Where did it go?"** *Students should know that substances do not just "disappear." Conservation of mass still holds here. The original molecules of PCE are converted to other molecules until eventually a relatively harmless molecule is formed. The article shows the series of products in the remediation of PCE—first trichloroethylene, then dichloroethylene, then vinyl chloride and finally ethylene, a gas. Ethylene, like many gases,*

is not very soluble in water (remember that the PCE contaminated underground water), so it will leave the aqueous phase and diffuse through the soil and into the atmosphere.

3. **"How long does bioremediation take before the site is cleaned up?"** *The article says that the Washington Square site took about 18 months to clean up. However, the clean-up time for any given bioremediation site depends on a variety of factors—the nature of the contaminant, forms of bacteria that are available at the site, required nutrients at the site, soil conditions (moisture, pH), temperature and many other variables.*

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

1. From Cornell University Inquiry Library, this online text on composting contains a number of research questions that students can pursue: http://compost.css.cornell.edu/CIC.html.
2. The University of Florida developed an online composting pile that students can manipulate at http://sarasota.ifas.ufl.edu/compost-info/tutorial/index.shtml.
3. This lab activity was designed as part of Cornell University's Inquiry Partnership in response to a nearby high school that had a chlorinated solvent spill discovered in the town. The lab is a safe alternative procedure that does not involve any toxic substances. (http://csip.cornell.edu/Curriculum_Resources/CSIP/Sills/Sills_Bioremediation.html)
4. This activity involves the aerobic breakdown of motor oil by soil bacteria: http://www.accessexcellence.org/RC/AB/BA/A_Students_Experiment.php.
5. This lab from the Chemical Heritage Foundation illustrates the breakdown of starch by soil bacteria: http://assets.chemheritage.org/EducationalServices/pharm/antibiot/activity/nameth.htm.
6. Science In The Real World: Microbes In Action Program developed a standard fermentation lab, which students can do as example of an anaerobic process. (http://www.microbeworld.org/index.php?option=com_content&view=article&id=348)

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

1. Students can manage a virtual compost pile in this online activity from the University of Florida: http://sarasota.ifas.ufl.edu/compost-info/cn/.
2. Bacteria play an important role in many processes. You could assign students to research some important roles played by both aerobic bacteria and anaerobic bacteria. Sites to use for starters include http://water.me.vccs.edu/courses/ENV149/lesson4b.htm or http://www.prevalentbacteria.org/bacteria.cfm .
3. Students can research other methods of soil or water bioremediation using a Webquest format (http://webquest.org/) . Three possible starting points are the U.S. Geological Survey site http://water.usgs.gov/wid/html/bioremed.html, the U.S. Environmental Protection Agency site http://www.epa.gov/tio/download/citizens/bioremediation.pdf, and the International Union of Pure and Applied Chemistry (IUPAC) site http://old.iupac.org/publications/pac/2001/pdf/7307x1163.pdf.

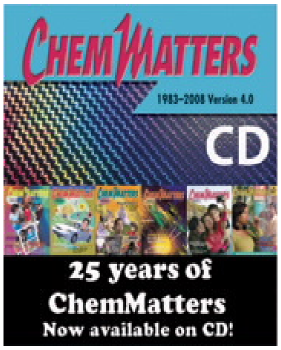
References (non-Web-based information sources)

Norris, R. *Handbook of Bioremediation*; CRC Press: Nashville, TN, 1993. Although dated (see following entries), this handbook presents information regarding the processes, application, and limitations of using remediation technologies to restore contaminated soil and ground water. The use of electron acceptors other than oxygen, natural bioremediation, and the introduction of organisms into the subsurface are among the specific topics covered.

Talley, J. (ed.). *Bioremediation of Recalcitrant Compounds*; University of Notre Dame Press: South Bend, IN, 2005. This text addresses the latest in bioremediation technologies for three difficult-to-treat contaminant groups: chlorinated solvents, PCBs, and PAHs - one of the most complex and expensive areas of applied remediation engineering.

Wise, D. et. al. (eds.). *Bioremediation of Contaminated Soils*; CRC Press: New York, NY, 2009. This volume focuses on innovative bioremediation techniques and applications for the cleanup of contaminated media and sites. It includes quantitative and design methods that elucidate the relationships among various operational parameters, and waste chemistry that defines the cost effectiveness of bioremediation projects. It also presents numerical models and includes chapters on remediation of soils contaminated with chlorinated solvents.

Bioremediation Journal; Taylor & Francis, Inc.: Philadelphia, PA. This is a peer-reviewed quarterly that publishes current, original laboratory and field research in bioremediation, the use of biological and supporting physical treatments to treat contaminated soil and groundwater. The journal rapidly disseminates new information on emerging and maturing bioremediation technologies and integrates scientific research and engineering practices. The authors, editors, and readers are scientists, field engineers, site remediation managers, and regulatory experts from the academic, industrial, and government sectors worldwide.



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 Web site screen, click on the *ChemMatters* CD icon like the one shown here 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.)

(http://www.acs.org/chemmatters)

Robson, D. Sunken Treasure, *ChemMatters*, April, **1987,** *5* (2), pp. 4-8. Although this article is about sunken treasure and not bioremediation, it contains a section that describes the reduction of sulfate ions in sea water by bacteria in an anaerobic environment created in a sealed chest on the ocean floor.

Holzman, D. Bacteria Power, ChemMatters, April, **2004** *22* (2), pp. 11-13. This article describes how bacteria can be used to produce electricity. One section of this article shows how the *Geobacter sulfurreducens* bacteria is able to produce an electric current by oxidizing acetate ions in an anaerobic environment at the bottom of a lake in a process similar to the bioremediation of PCE in the current article.

Web Sites for Additional Information (Web-based information sources)

More sites on bioremediation

The U. S. Environmental Protection Agency and its Office of Solid Waste and Emergency Response prepared this detailed overview of *in situ* bioremediation of sites like Washington Square.
http://www.cluin.org/download/studentpapers/moretti_dnaplbioremediation.pdf

This "Citizen's Guide to Bioremediation" comes from the Environmental Protection Agency: http://www.clu-in.org/download/citizens/bioremediation.pdf.

An overview of various types of dry-cleaning site bioremediation methods can be found at http://www.iet-inc.net/techLiterature/Technical%20Bulletin%20-Dry%20Cleaners.pdf.

The United States Geological Survey gives some examples of bioremediation here: http://water.usgs.gov/wid/html/bioremed.html.

This online essay and interview describes bioremediation in not-so-technical terms: http://www.bic.org.my/BICnews/BICnews9.pdf.

This extensive report from the Interstate Technology and Regulatory Council includes a general description of bioremediation, contamination sources and properties, bioremediation geochemistry and hydrogeology along with the stoichiometry of bioremediation processes. (http://www.itrcweb.org/Documents/ISB-8.pdf)

IUPAC published a complete overview of bioremediation that includes principles, microbial populations, types of contaminants, environmental factors, and strategies. View it at http://old.iupac.org/publications/pac/2001/pdf/7307x1163.pdf.

This video describes a method of bioremediation using beeswax (the stuff used to make those fake teeth and lips some of us wore as kids), developed by NASA for use in cleaning up oil spills: http://www.youtube.com/watch?v=zmSaNqMpfCs.

More sites on oxidation-reduction

This web site is a tutorial on oxidation-reduction reactions:
http://www.shodor.org/unchem/advanced/redox/

Information about oxidation numbers and balancing redox reactions can be found here: http://www.files.chem.vt.edu/RVGS/ACT/notes/oxidation_numbers.html.

Here is a series of videos from Khan Academy about redox:
Introduction to Oxidation Numbers
http://www.youtube.com/watch?v=_fNNQfGGYr4&list=PL166048DD75B05C0D&index=55&feature=plpp_video
More on Oxidation States
http://www.youtube.com/watch?v=GA88JI4AymY&list=PL166048DD75B05C0D&index=56&feature=plpp_video

Redox Reactions
http://www.youtube.com/watch?v=yp60-oVxrT4&list=PL166048DD75B05C0D&index=58&feature=plpp_video

This 41-page ebook gives a complete textbook-like description and explanation of oxidation and reduction. (http://ebookbrowse.com/bishop-book-6-ebook-pdf-d22129458)

More sites on perchloroethylene

The United States Environmental Protection Agency prepared this chemical summary of perchloroethylene: http://www.epa.gov/chemfact/s_perchl.txt.

This monograph gives an overview of perchloroethylene with technical information about the substance in the context of the dry-cleaning process: http://www.agls.uidaho.edu/etox/resources/case_studies/PCE_DRY.PDF.

More sites on soil bacteria

This online article from Ohio State University summarizes characteristics of soil bacteria: http://ohioline.osu.edu/sag-fact/pdf/0013.pdf.

This site, sponsored by American Society for Microbiology, provides information about many different types of bacteria: http://www.microbeworld.org/index.php.

Microbe World site has resources, news, videos and photos about microbes, including bacteria, at http://www.microbeworld.org/index.php.

From Fish Tank to Fuel Tank

Background Information (teacher information)

More on biofuels

The *ChemMatters* article focuses on the use of algae as a source material for producing diesel fuel for motor vehicles and possibly airplanes. Algae can also be a starting material for producing another category of fuel, alcohols. Although ethanol is most often mentioned, butanol is being touted as a better alternative to ethanol.

- It can be blended with gasoline at up 16% rather than the lower value of 10% for ethanol.
- It has a superior energy content compared to ethanol, which translates into better fuel economy. The extra 2 carbon atoms per molecule give a 25% increase in energy.
- It produces lower volatile organic compounds (VOC) than ethanol when blended with gasoline.
- It is less corrosive than ethanol and is less susceptible to separation in water compared with ethanol (which is important in storage as well as transport).

The approach to using alternative fuels that are not petroleum-based comes under the rubric of biofuels or bioenergy, most of which is derived from plants (biomass). As mentioned, the more familiar biofuel of the last decade is ethanol, derived primarily from corn. This process has been promoted and, therefore, subsidized by the federal government, artificially supporting the true price of producing the alcohol. There are many critics of this alternative fuel promotion with a whole host of questions, including whether or not it takes more energy to produce the ethanol than is contained in the fuel itself and how much carbon dioxide is put into the atmosphere from the cultivation and processing of the corn, as well as from the actual combustion of the alcohol in an automobile or truck engine.

One issue that is not in dispute is the effect on food prices of producing ethanol, because of growing a food crop (animal feed) that is then diverted to fuel production. When there is competition for a food crop as in food versus fuel, the price and availability of food is affected. There is ample evidence for that. To reduce this impact, there has been research into using cellulose rather than the starch of plants for producing, through fermentation, ethanol, methanol, and butanol fuels. Cellulose comes from those parts and kinds of plants that are normally not associated directly or indirectly with human consumption. The source of this cellulose is often from the part of plants not eaten by animals. This includes the stems of grass plants such as switchgrass or the waste products from wood processing (think wood chips). There is also great interest in using sugar cane as the source of cellulose, utilizing special bacteria for digestion and production of butanol rather than ethanol. DuPont and British Petroleum (BP) have a joint venture in Brazil to mass-produce butanol from sugar cane. Two types of bacteria are used to first convert glucose (enzymatically derived from the cellulose, a glucose-based polymer) into butyric acid, then converting the acid to butanol.

What is becoming of more interest is to find other types of fuels for combustion that are not derived from petroleum and do not depend on food crops as the carbon source. Again, we are talking about fuels that are derived from non-food plants, hence biofuels. More specifically, oils found in plants can be converted to a fuel with the properties of diesel fuel and is called biodiesel.

More on biodiesel

It is possible, through fairly simple processes, to change plant-derived oils into diesel fuel. There are many different plants that can provide the oil—this is nothing new. We are all familiar with cooking oils such as canola and soybean oil. But again, if one wants to convert these oils into biodiesel, we are diverting a food crop to a transportation fuel. And that continues to be a problem as has been clearly delineated with the promotion of ethanol from corn. But there are currently non-food crops that produce oil, specifically single cell algae.

The U.S. government has actively promoted the development and use of biofuels and other alternative fuels over the last 20-plus years. (Alternative fuels include hydrogen, electricity, natural gas, propane, ethanol and biodiesel) The idea, of course, is to find fuel sources to replace those that come from fossil fuels, particularly petroleum. In the government publication *Renewable Fuels Standard (RFS)* a detailed and documented argument is set out for developing biodiesel derived from non-food algae to replace petroleum-based diesel fuel. Information about the *Renewable Fuels Standard* (*RFS*) is found in a publication, "The Promise and Challenge of Microalgal-derived Biofuels" from the National Renewable Energy Laboratory, available at http://www.afdc.energy.gov/afdc/pdfs/microalgal_biofuels_darzins.pdf. Excerpts containing important information follow.

> The RFS calls for the production of 36 billion gallons by 2022 of which at least 21 billion gallons must be advanced biofuels (i.e., non-corn ethanol). While cellulosic ethanol is expected to play a large role in meeting the EISA goals, a number of other advanced biofuels show significant promise in potentially helping to achieve the 21 billion gallon mandate. Of these candidates, biofuels derived from algal biomass feedstocks are generating considerable interest around the world. It is with this in mind that microalgal-derived lipids could serve as a major contributor to our goal of energy independence. There are several aspects of algal biofuel production that have combined to capture the interest of researchers and entrepreneurs around the world.
>
> These include:
> i) high per-acre productivity, ii) algal feedstock based on non-food resource, iii) use of otherwise nonproductive, non-arable land, iv) utilization of a wide variety of water sources (fresh, brackish, saline, and wastewater), v) mitigation of GHG release into the atmosphere, and vi) production of both biofuels and valuable co-products.
>
> The development of biofuels from traditional oil crops and waste cooking oil/fats cannot realistically meet the demand for transportation fuels. If the entire 2007 U.S. soybean oil yield, representing almost 3 billion gallons produced on 63.6 million acres of farm land (Soy Stats™, American Soybean Association, available at http://www.soystats.com) was converted to biofuel, it would replace only about 4.5% of the total petroleum diesel (~66 billion gallons).
>
> If that much land were used to cultivate algae, the resulting oil could, even at a conservative projected productivity (10g/m^2/day at 15%

> triacylglycerols or TAG), replace approximately 61% of the petroleum diesel used annually (Table 1), as well as capturing approximately 2 billion tons of CO_2 in the biomass. CO_2 capture, however, should not be confused with CO_2 sequestration since a portion of the CO_2 captured and partitioned in the oil will be released when the algal-derived fuel is combusted, and the remaining biomass will likely be used as a feedstock for a byproduct that will ultimately be converted to CO_2. Algal capture of CO_2 for biofuels applications really amounts to a 'recycling' of the CO_2 for at least one additional use prior to being released during burning of the fuel. Under this scenario, there is no permanent CO_2 capture unless the algal biomass is completely isolated from the environment and stored."
> (http://www.afdc.energy.gov/afdc/pdfs/microalgal_biofuels_darzins.pdf, pp 432, 433)

Data comparing productivity of soybeans vs. algae:

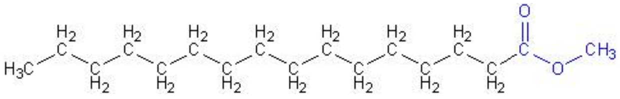
	Soybean	**Algae**		
Productivity		Low Productivity	Medium	High
		10 g/m^2/day	25 g/m^2/day	50 g/m^2/day
		15% TAG	25% TAG	50% TAG
Gal/acre	48	633	2637	10,549
Total Acres	63.6 million	63.6 million	25 million	6.26 million
Gal/Year	3 billion	40 billion	66 billion	66 billion
%Petrodiesel	4.5%	61%	100%	100%

(http://www.afdc.energy.gov/afdc/pdfs/microalgal_biofuels_darzins.pdf, p 434)
NOTE: TAG is Triacylglycerols

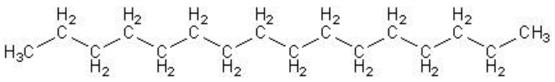
More on the chemistry of biodiesel

Biodiesel from plant-derived oils is based on the standard chemical process of esterification. Essentially, one combines an oil with an alcohol in the presence of some alkali such as sodium or potassium hydroxide. Heating the mixture converts the oil into an ester (the biodiesel) and glycerol. As will be referenced later, students can easily perform this experiment in the laboratory. (Reaction of vegetable oil with alkali is shown below.)

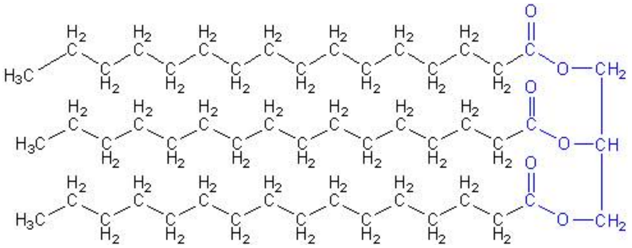
Vegetable oil, like biodiesel, belongs to a category of compounds called *esters*.



Molecule of biodiesel (with ester group on end in blue):

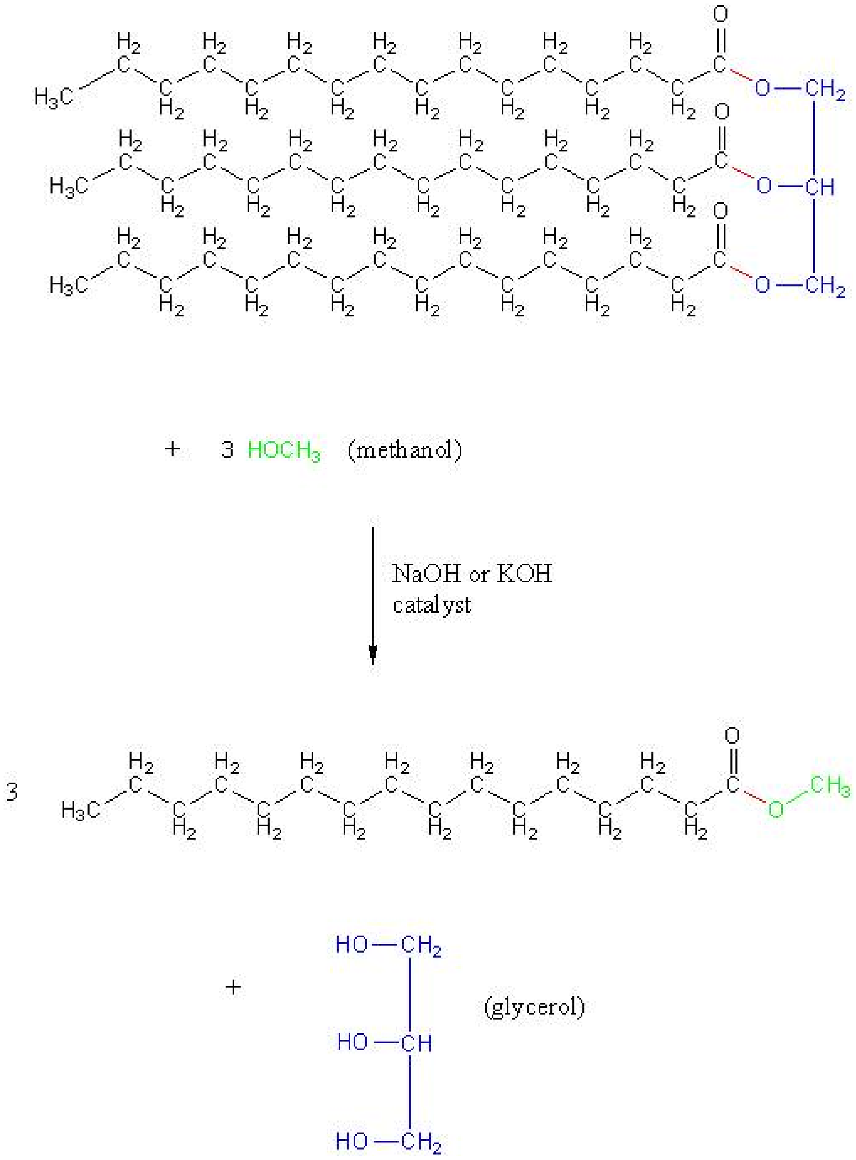


Molecule of regular diesel, a hydrocarbon



Molecule of vegetable oil

“Therefore, converting vegetable oil into biodiesel is called a *trans-esterification reaction*. Doing this reaction requires using methanol (shown in green [in the diagram below]), which causes the red bonds in the structure below to break. This breaks off the blue section, like a backbone on the molecule, which becomes glycerol. The red bonds that did go to the glycerol backbone are placed with bonds to methoxy groups (shown in green in the final structure) that came from the methanol:”



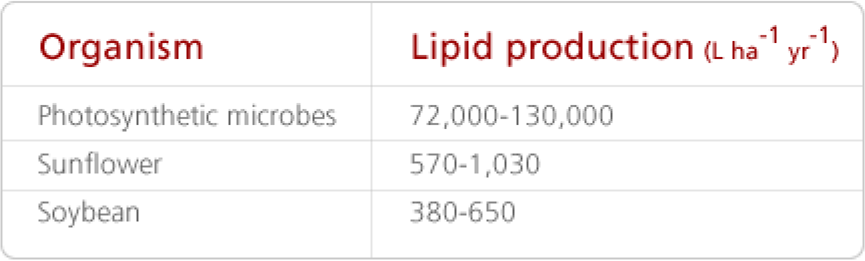
(Goshen College Department of Chemistry website, http://www.goshen.edu/chemistry/biodiesel/chemistry-of/)

Currently, the search is on for the most economical methods for both producing the oil and converting it to biodiesel. As mentioned, there is currently keen interest in the use of algae rather than food crops such as soybean and canola seed. Further there is a good argument to locate these algae-culturing units close to a source of carbon dioxide such as a power-generating plant that burns coal, oil, or natural gas. The algae cultures become a carbon sink for the emissions of the electricity generating plant, therefore adding a second dimension to developing oils for fuel. One of the current U.S. government policies concerning the production and use of biofuels is that these fuels must achieve at least a 50% reduction in life-cycle greenhouse gas emissions. This is not possible using fossil fuels since these fuels, although plant derived, are not currently utilizing carbon dioxide in their production! They simply produce carbon dioxide in their combustion. Presently living plants that eventually become biofuels absorb as much if not more carbon dioxide than they eventually produce if “burned” or biologically decomposed.

More on biodiesel from algae

There are many benefits from using algae as the source of plant lipids for conversion to biodiesel. Cultivation of algae is done in water rather than growing on land, obviously. The cultivation is done in closed-loop structures to eliminate contamination from other air-borne algae. With these closed loop set-ups, cultivation is under controlled conditions of temperature, light intensity, carbon dioxide concentrations (higher than from the normal atmosphere), pH, and nutrient levels. Certain physical arrangements also increase the surface area exposed to light using transparent vertical growing tubes. There is a good video on the production of algae under controlled (indoors) and more efficient (vertical tubes, multiple-side exposure) conditions than open ponds; see http://www.5min.com/Video/Algae-as-a-Green-Solution-to-the-Worlds-Energy-Problem-255719725.

Land-based crops require much more acreage than algae cultivation apparatus, even if in the form of covered ponds. Further the algae growth time to produce an amount of oil when compared with land-based crops is significantly less. The Department of Energy (DOE, U.S.) reports that algae yields 30 times more energy per acre than land crops such as soybeans. Some numbers suggest 100,000 barrels of oil per acre from algae versus 20,000 barrels of corn-based ethanol per acre. Considering just oil production from various crops, the numbers below make the case for algae-produced oil.



Organism	Lipid production (L ha^{-1} yr^{-1})
Photosynthetic microbes	72,000-130,000
Sunflower	570-1,030
Soybean	380-650

Table 1. Comparison of lipid production ranges per hectare per year for microalgae and oil-producing plants.

(http://biofuels.asu.edu/tubes.shtml)

More on extraction techniques for algae-based biodiesel

Extraction of oil from algae can be done one of three ways—use of an oil press, supercritical fluids, or the solvent hexane.

The oil press is the most direct and easiest method. As in extracting oil from olives, the process yields up to 75% of the oil found in the algae.

The use of supercritical fluids extracts up to 100% of the oil in the algae. In this process, carbon dioxide is used. It is pressurized and heated to produce a liquid as well as a gas. The algae is mixed with the supercritical carbon dioxide and the algae turns completely into oil. The equipment required for this process makes it a less popular option for extraction.

The use of cyclohexane as a solvent is a two-part process. First the algae is put through the presses. The leftover algae is then mixed with cyclohexane and the mix is filtered, separately removing the residual cyclohexane. The cyclohexane and oil are separated by distillation, by which 95% of the oil is recovered.

More on alternate methods for converting waste vegetable oil

Some investigators have been exploring more efficient ways to convert plant oils to biodiesel by operating at lower temperatures with the use of two catalysts, bismuth triflate and scandium triflate, which eliminates the need to use, in separate reactions, sulfuric acid and potassium hydroxide. A description of the technique can be found at http://www.futurity.org/earth-environment/kinder-faster-biodiesel-conversion/. The sulfuric acid converts the fatty acids in the vegetable oils to biodiesel, and the potassium hydroxide converts triglyceroles to biodiesel.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Lipids—**Both the fats (animal source) and oils (plant source) in lipids are starting molecules to be converted to biodiesel through the ester formation process (esterification).
2. **Esterification—**Because lipids contain triacylglycerols or triglycerides, these molecules can be broken apart using an alcohol in a basic reacting environment (the esterification process) to form a molecule dubbed biodiesel (the ester), and glycerin which can be used in the soap-making industry as well as an additive to animal feed.
3. **Combustion—**In order for biofuels to be used as an energy source to produce mechanical motion in a vehicle, the biofuels must possess potential energy that can be released upon combustion, heating the gaseous products of combustion. Fuel, oxygen and kindling temperature are the basic ingredients of burning or combustion, and explosions occur as a result of rapid combustion reactions in a confined space. These concepts fit into the curriculum when discussing molecular bonding, bond energies, exothermic and endothermic chemical reactions, and the gas laws.
4. **Explosions—**Explosions are merely rapid combustion reactions that happen in an enclosed space where pressure can build up. This is the basis for creating motion within the internal combustion engine that is translated to additional mechanical motion of a vehicle.
5. **Rates of Reactions**—In order to be useful as a biofuel, the configuration of an engine running on biofuel must be such that there is enough compression of the fuel (its flash point) in order to combust. This is particularly true for diesel engine fuel. Combustion of the fuel and oxygen mixture depends on rapid compression which accelerates the gaseous particles, which means a higher temperature and the ignition of the fuel. (There is no spark for initiating the reaction.) The rate of a combustion reaction is determined by the amount of fuel, the size of the fuel particles, the amount of available oxygen and, for a diesel engine, the speed of contraction of the fuel mix in the cylinder.
6. **Thermodynamics/Thermochemistry—**Explosions are prime examples of heat production and the rate of heat production in chemical reactions. These reactions can be related to the relatively high heat content of the reactant fuels compared to the much lower heat content of the products.
7. **Petroleum—**Petroleum is a mixture of different kinds of hydrocarbons and other organic molecules that can be separated out by distillation. Petroleum has been produced most likely from extreme pressure on dead and decaying plant material, including algae. Some species of algae found as fossils in petroleum (and coal) are the same types now being used to produce the oil for biodiesel synthesis.
8. **Viscosity—**Because of the viscosity of diesel fuel, provision must be made to warm the fuel in order to flow better to the engine as well as to vaporize the fuel.

9. **Hydrocarbons—**These types of molecules are good fuels because of the carbon-hydrogen content that leads to production of water and carbon dioxide with a net ΔH that is negative. Coal, which is essentially pure carbon and not a hydrocarbon, produces less energy per mole because of the lack of hydrogen for producing water.
10. **Kinetic molecular theory—**Chemical reactions of biofuels in an engine depend upon molecular collisions that cause bonds to break and new ones to form. The compression of the fuel and its subsequent heating both contribute to the colliding of the molecules of biofuel vapor with oxygen gas causing an exothermic reaction from the sum of bond breaking and bond making. That in turn produces more kinetic motion of the gaseous products causing an expansion of the gas volume which produces mechanical energy of the engine.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"The energy produced by burning biodiesel or other fuels comes from the breaking of chemical bonds, releasing bond energies."** *Breaking bonds* ***requires*** *energy; forming bonds* ***releases*** *energy. Burning a fuel is a combustion reaction which, like other exothermic reactions, results in a net output of energy (heat, light) due to both the breaking of chemical bonds (input of energy or endothermic reaction) and the making of bonds (output of energy or exothermic reaction). The sum of these two energy changes equals the net energy change in the system. In the case of combustion, the net energy change is exothermic or a net output of energy in the system.*
2. **"If chemical bonds produce heat when broken, they must contain heat."** *Chemical bonds between atoms within a molecule are due to the sum of the forces of attraction and repulsion, creating positions with distance between the atoms. These atomic bonding positions determine the bond's potential energy or energy of position. A change in the distances between the atoms means a change in potential energy which is associated with the making and breaking of bonds. The sum of the potential energy changes in making and breaking of bonds results in the amount of heat energy of the combustion reaction.*
3. **"Temperature and heat are the same thing."** *Temperature is a measure of molecular motion. Heat is a form of energy that flows across a conducting boundary from the higher to the lower temperature. Temperature is measured in kelvins (or degrees Celsius), while heat is measured in kJ.*
4. **"If a reaction mixture gets hot, the reaction mixture must be endothermic."** *If a reaction mixture becomes hot, it is not due to absorbing heat but because the reaction is generating heat (exothermic) in the mixture. Heat flows out of the system into the surroundings. One needs to distinguish between system (loses energy) and surroundings (gains energy and becomes warmer).*

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

1. **"How is oil from plants different from oil out of the ground (petroleum)?"** *Oil from the ground or petroleum is a mixture of different organic compounds that can be separated out by distillation. The origin of these compounds is thought to be from the chemical conversion of plant material, particularly different types of algae, including the single-celled algae used*

to provide the oils used in biodiesel conversion. Oil in plants is also a mixture of different organic compounds with the predominant molecule being a mono-alkyl ester of long chain fatty acids. The major difference as it relates to global warming is that burning oil from petroleum releases massive amounts of carbon dioxide into the environment, while burning oil from plants growing today results in carbon-neutrality—the amount of carbon absorbed from the air by the plant as it grew just balances the amount of carbon dioxide that is released back into the air when we burn the plant-derived oil.

2. **"Why is biodiesel considered to be a cleaner fuel than diesel derived from petroleum?"** *Burning biodiesel produces fewer unburned hydrocarbons, carbon monoxide and particulate matter compared with petroleum-derived diesel. In addition, exhaust emissions of sulfur oxides and sulfates are essentially absent from biodiesel.*
3. **"If biodiesel contains carbon, why is it considered a better fuel for reducing carbon emissions and its contribution to global warming than regular diesel?"** *It is estimated that biodiesel reduces net carbon emissions by 78 per cent, due to biodiesel's closed carbon cycle, that is, the carbon dioxide given off originally came from the atmosphere and was incorporated into the plant tissue that produced the oil used to make biodiesel; the carbon dioxide emitted when the biodiesel is burned will again be taken up by plants. Petroleum did not remove carbon dioxide in recent times as biodiesel-producing plants have done. So petroleum is simply adding carbon dioxide to the atmosphere, not recently removing carbon dioxide as the petroleum formed.*
4. **"Does biodiesel take more energy to make than it gives back?"** *Calculations suggest that for every unit of fossil fuel energy used to make biodiesel, 4.5 units of energy are produced when it burns. This takes into account the planting (growing), harvesting, fuel production and fuel transportation to the end user.*

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

1. It is not difficult to make biodiesel* in the school laboratory. After making it, students can test the energy value of the biodiesel and compare with some other fuels, including ethanol and a higher carbon fuel such as kerosene or candle wax. They could also compare the energy value of cooking vegetable oil which is used to make the biodiesel. The standard method for determining the joule value of each fuel is to set up a calorimeter, using a soda can containing water, suspended over the fuel source. For the liquid ethanol, biodiesel and kerosene, use flint glass "alcohol" burners available from school science supply companies. But **be careful** not to have any open containers of the fuel in the lab area near the open flames. A simple procedure for making biodiesel can be found in the most recent *Chemistry in the Community (ChemCom)* textbook (5th ed., 2006, ISBN 0-7167-8919-1, pp 286-288). A more involved biodiesel laboratory exercise is found at http://www.teachbiofuels.org/biodiesel%20lessons%202007/Stoichiometry_%20Making%20Biodiesel%20(single%20phase).pdf.
2. Students could produce the biofuel ethanol through the fermentation process. In this exercise, students could determine the optimum conditions for fermentation, including pH, temperature, type of substrate (various sugars including glucose, sucrose, lactose, fructose) keeping the same type of yeast. Determining the optimum conditions means that students would measure the rate of fermentation, using computer-based lab probes to measure gas pressure over a short period of time (roughly 10 minutes). This would be a closed system. If your lab probe program includes real time graphing, the data can also be used by the students to produce a hard copy of the data and graph for analysis (rate also calculated by

the computer program). What are the optimum conditions for fermentation with each type of sugar? Does the size of the sugar molecule have any relationship to the rate?

3. If students do the fermentation lab (activity #2), they could also isolate the alcohol using small scale distillation (250 ml flask with delivery tube and thermometer); the ethanol could be evaluated for density, flammability, boiling point (temperature data from the distillation process) and its joule value, using the procedure in activity #1 above.
4. Demonstrate the principle of the diesel engine (compression ignites fuel) with a fire syringe (available at Educational Innovations: http://www.teachersource.com/Energy/EnergyConversion/FireSyringeDemo.aspx).
   Several videos show the fire syringe in operation, including one at the above website; see other examples at http://video.google.com/videoplay?docid=5308173995304909609# and http://www.youtube.com/watch?v=MnpvQvCTj90.
5. The effect of the number of hydroxyl groups on viscosity due to the increasing number of intermolecular bonds can be shown by slowly pouring, separately, several three-carbon alcohols with different numbers of hydroxyl groups. Use 1-propanol, 1,2-propanediol, (propylene glycol, found in some anti-freeze formulations), and 1,2,3-propanetriol or glycerol (one of the products resulting from the trans-esterification of plant oils when making biodiesel).
6. An interesting video that combines some elements on the periodic table with future material generation using non-petroleum sources (focus is on the car—its fuel and structural materials) comes from the current (2011) PBS NOVA program on “Stuff”, in particular, the second program titled “Making Stuff Cleaner”. The program can be viewed at any PBS station’s website under NOVA programs. (http://video.pbs.org/video/1768954299)
7. Several videos that show the cultivation of algae and its attendant technical problems can be found at the following websites: http://www.youtube.com/watch?v=k4z7p8-4oGo&NR=1, http://www.youtube.com/watch?v=hGcLgE52rzw&feature=fvw, and http://www.youtube.com/watch?v=EmiNcxbpFnI.
   A video of a college PowerPoint lecture (7 minutes) on algae culture that is very comprehensive can be found at http://www.youtube.com/watch?v=cAVJN0-gUTw&feature=related.
8. If your course includes a discussion of bond energies and estimating enthalpies of reaction from bond energies, you could assign the following problem:
   The density of gasoline is 0.78 g/mL. The density of regular diesel fuel is 0.85 g/mL. A gallon is equal to about 3.8 L. Given the following average bond dissociation energies:
   C-C (347 kJ/mol)
   C-H (413 kJ/mol)
   O=O (495 kJ/mol)
   C=O (799 kJ/mol)
   H-O (467 kJ/mol)
   and assuming that gasoline can be represented by the formula C_8H_{18} and diesel fuel by the formula $C_{14}H_{30}$, estimate the number of joules of energy that would be released when one gallon of gasoline and one gallon of diesel fuel are burned. Assume the only products of the reactions are gaseous carbon dioxide and water vapor.
   Alternately, even less information could be given and students could be expected to look up or calculate some of the required information. Stating the problem with minimal information one might ask:
   Using average bond dissociation energies, estimate and compare the amount of energy released when one gallon of gasoline and one gallon of diesel fuel are burned. Assume their respective formulas are C_8H_{18} and $C_{14}H_{30}$, and the only products of the reactions are carbon dioxide and water vapor.

9. A Web Quest on "Alternative Biofuels" by high school chemistry teacher Ron Brandt is available at http://web-prod-1.shu.edu/~brandtro/indexAF.html. The student is tasked with working as part of a team of four students to research and report to the President (of the U.S.) about either ethanol or biodiesel as an alternative to fossil fuels. A 3-week timeline is given, with interim reports required at specified intervals. This is very professional looking, with specific requirements for each step, and an evaluation rubric included. An added feature to this site is a blog that students can access to discuss their findings with others and the "President", and to report progress. (Unfortunately, this is an in-school feature and not available to outside access; nonetheless, it is a worthwhile item to consider in your own class work.)

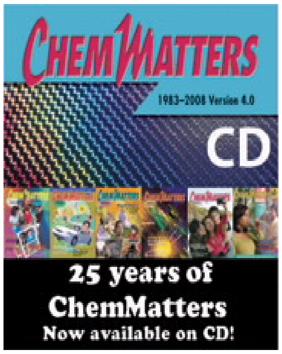
Out-of-class Activities and Projects (student research, class projects)

1. Students could evaluate what parts of the visible spectrum are most effective (efficient) in photosynthesis of algae. First they need to establish how the photosynthetic process can be evaluated in terms of rate of reaction. To make this truly inquiry-based, you could have students do their own research to determine how to investigate the problem. Alternatively, you could give them this procedure:
   Use large size test tubes as algae incubators, with a delivery tube attached to each test tube through a one-hole stopper. The delivery tube will be attached to an oxygen sensor (computer-based lab probe) for measuring rate of production of oxygen gas during photosynthesis. The individual tubes will be placed in a water bath, preferably in a transparent rectangular container that can hold water to maintain a constant temperature. Between a strong light source (flood lamp) and the water bath container will be placed various cellophane filters (see your local theater department; otherwise, check with Kodak for known filter values that are available) Source of inexpensive cellophane paper is http://www.hyglossproducts.com/Cello-Wrap-Rolls-p/71501-1.htm. Students must make sure the intensity of the various wavelengths of light is constant through the use of a light meter, varying distance from light source to reacting chamber.
   Also there is an abstract of a student's photosynthesis experiment at http://www.usc.edu/CSSF/History/2006/Projects/J1610.pdf. It provides the set-up details including the chemical environment provided for photosynthesis to take place.
   An excellent simulation (animation) of the photosynthesis process at the cellular level with the ability to manipulate the intensity of light and the particular wavelengths used can be found at http://www.mhhe.com/biosci/genbio/biolink/j_explorations/ch09expl.htm. There is an accompanying lab exercise (including scoring rubric) using the data collected in the simulation that can be found at http://www.biologycorner.com/worksheets/photosynthesis_sim.html.
   Another lab exercise reference that could be used to set up the original experiment to see the effect of various wavelengths of light on photosynthesis, using various probes for light intensity, % oxygen produced and temperature range used is found at http://www.fourier-sys.com/pdfs/new_experiments/nova_biology/photosynthesis.pdf. There is a very good picture to show the setup of the equipment.
2. Students could research the various alternate fuels for transportation, including biofuels, in terms of cost, and viability (why they could be useful or possible). Start with the government website on Alternate Fuels http://www.afdc.energy.gov/afdc/about.html, and http://www.afdc.energy.gov/afdc/fuels/index.html . Another site is found at http://www.rsc.org/chemistryworld/Issues/2009/April/Thebiofuelfuture.asp and http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/ (biodiesel performance, costs, and use)

3. Students could research and report on the various commercial cultivation methods and parameters for algae Students should evaluate the various methods of cultivation—on what basis is one cultivation method preferred over another. Consider location (the ocean vs. ponds vs. indoor tanks). What are the positives and negatives? This includes costs for the various setups and the methods for preventing contamination of the culturing environments. Is algae production and processing more expensive than land-based crops such as cellulolytic crops (non-food grasses)? They can start their research here: http://www.oilgae.com/algae/oil/biod/cult/cult.html.
   References for extraction of oils from algae (chemical, mechanical) can be found at http://www.oilgae.com/algae/oil/extract/mec/mec.html and http://www.oilgae.com/algae/oil/extract/che/che.html.

References (non-Web-based information sources)

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 Web site 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 <u>and</u> Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Nolte, B. The Many Lives of Cooking Oil. *ChemMatters* **2011***, 29* (2), pp 5-7. This article looks at using plant-derived oil directly in an automobile engine with modifications, making an argument for recycling cooking oil. The article also provides background on the workings of a diesel engine vs. a gasoline-powered engine, converting chemical potential energy to mechanical energy.

Schirber, M. Green Gasoline: Fuel from Plants. *ChemMatters* **2010**, *28* (1), pp 13-15. The author discusses the chemical processes by which the cellulose of plant material is converted to various compounds found in gasoline. The Teacher's Guide for this article provides additional background for the teacher and can be accessed at the ChemMatters online site http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/CNBP_026994

Kirchhoff, M. Do You Want Biodiesel with That? *ChemMatters* **2005**, *23* (2), pp 7-9. The author discusses the chemistry of biodiesel, its synthesis and its use as a fuel to be blended with petroleum-derived diesel fuel. Discussion focuses on soybean oil as the source for conversion (trans-esterification) to biodiesel, with chemical (structural formulas) reaction diagrams. Current thinking is not to use soybeans since they are a food source also (see background information).

Alper, J. Rudolph Diesel's Engine, *ChemMatters*, **1990**, *8* (4), pp 11-13. This is a complete biography on Diesel's life, including the design and use of his invention, the diesel engine.

The *Chemistry in the Community (ChemCom)* textbook has a unit on petroleum (including alternate fuels and a biodiesel lab exercise): *Chemistry in the Community,* American Chemical Society: Washington DC, 5th ed., 2006, ISBN 0-7167-8919-1.

Web Sites for Additional Information (Web-based information sources)

More sites on biofuels from biomass

A comprehensive overview of converting biomass to useful fuels, particularly ethanol, is found at http://www.rsc.org/chemistryworld/Issues/2009/April/Thebiofuelfuture.asp.

A government roadmap for using algae as the source of biofuels is found at http://www.technologyreview.com/energy/25695/page1/.

A very extensive collection of references (links) on fuels from biomass can be found at http://www.altenews.com/biomass.htm.

More sites on biodiesel

All the facts about biodiesel, including the entire commercial process (flow chart), as well as its physical and chemical properties, can be found at http://www.biodiesel.org/pdf_files/fuelfactsheets/prod_quality.pdf.

More sites on algae production using nanoparticle-enhanced light

An interesting idea using nanoparticles to enhance the photosynthesis process through the selective reflection of the most efficient wavelengths of light in an algal culture is described at *Futurity*'s website, http://www.futurity.org/earth-environment/grow-light-may-give-algae-biofuel-edge/.

More sites on alternate methods for converting waste vegetable oil

Some investigators have been exploring more efficient ways to convert plant oils to biodiesel by operating at lower temperatures with the use of two catalysts, bismuth triflate and scandium triflate, which eliminates the need to use, in separate reactions, the sulfuric acid and potassium hydroxide. A description of the technique can be found at http://www.futurity.org/earth-environment/kinder-faster-biodiesel-conversion/.

More on alternate microorganisms (E. *coli*, algae) to produce biodiesel

This *Scientific American* Web site, http://www.scientificamerican.com/article.cfm?id=bacteria-transformed-into-biofuel-refineries, provides an article on bioengineering the bacterium E. *coli* for biofuel synthesis, eliminating both the oil extraction process and the subsequent esterification procedure for algal oils. The engineered *E. coli* first enzymatically digests/converts plant cellulose into sugar molecules that are then converted to biodiesel directly. The biodiesel floats to the top of a bioreactor vat, where it can be physically removed rather than depending on distillation for separation, which is an additional energy expenditure.

A similar biological approach using genetically altered algae rather than bacteria is detailed in the following articles: http://green.blogs.nytimes.com/2010/05/04/banking-on-fuel-sweating-flora/?scp=1&sq=%22%20...%20Fuel-Sweating%20Flora%22&st=cse and http://www.technologyreview.com/energy/25077/.

More sites on integrating algae cultivation with waste treatment plants (municipal and industrial)

Using algae for wastewater treatment offers some interesting advantages over conventional wastewater treatment. The advantages of algae-based treatment include: cost effective treatment, low energy requirement, reduction in sludge formation and production of algal biomass. See the following Web site for additional references that elaborate on the above rationales for algae-based waste treatment from which algae can be harvested for oil extraction: http://www.oilgae.com/algae/cult/sew/sew.html.

An excellent Power Point, with good explanatory details that could be used in classroom shows the pluses and minuses of a scheme for using algae in waste treatment plants. The Power Point can be accessed at http://www.nrel.gov/biomass/pdfs/lundquist.pdf.

More sites on algae cultivation near power plants

Algae cultivation near fossil-fuel-burning power plants allows for capture of carbon dioxide emissions that normally would go into the air, and using the gas for photosynthesis in algae for oil production and subsequent biodiesel production. A complete description of this arrangement and rationale can be found at http://www.oilgae.com/algae/cult/cos/pow/pow.html. The site includes a flowchart that illustrates the capture of carbon by algae, and the collection and trans-esterification of the algae oil to produce biodiesel.

More sites on ethanol feedstock resources

This U.S. government Web site, http://www.afdc.energy.gov/afdc/ethanol/feedstocks_resources_national.html, provides an extensive amount of data on the potential U.S. biomass feedstock resources that could be used in place of food crops for producing ethanol biofuel.

This Web site provides a U.S. map for location and details of biomass available for biofuel production, particularly ethanol: http://www.nrel.gov/gis/biomass.html.

A complementary map showing biomass resources per square kilometer in the U.S. is found at http://www.afdc.energy.gov/afdc/ethanol/feedstocks_resources_state.html.

More sites on the workings of an internal combustion engine

If students are interested in seeing the internal workings of the 4-stroke internal combustion engine, you can show them the “real deal” in an animation at http://www.carbibles.com/fuel_engine_bible.html. It can even be enlarged to full-screen model! And the text is there to describe what’s happening.

Another source of information and animations about car engines is the “How Stuff Works” site at http://auto.howstuffworks.com/engine.htm.

Recycling Aluminum: A Way of Life or a Lifestyle?

Background Information (teacher information)

More on the history of aluminum

As elements go, aluminum is a fairly recent discovery. Its compounds had been known for centuries. Alum, aluminum potassium sulfate [$KAl(SO4)_2$] was used as a mordant to fix dyes all the way back to the times of the Egyptians. Clays containing aluminum silicates were used for their strength by potters in Persia. And aluminum sulfate [$Al_2(SO_4)_3$] was used as an astringent by ancient Greeks to stop the flow of blood in wounds, much like its use today in styptic pencils.

The first isolation of a very tiny amount of aluminum metal was done by Hans Christian Ørsted in 1825. He heated potassium amalgam (mixture of potassium and mercury) with aluminum chloride and distilled off the mercury, produced tiny pieces of impure aluminum. Earlier, Humphrey Davy had used electrolysis of molten compounds to produce samples of sodium, potassium, calcium, strontium, barium, magnesium and boron. He had tried unsuccessfully to produce aluminum from clay by the same method. Even though he was unable to produce the element, he predicted its existence and named the element "alumium", ending like other elements Davy discovered and named—potassium, sodium, magnesium, calcium and strontium. By the time his 1812 book *Chemical Philosophy was published*, he had changed the name to "aluminum". (The name was later changed to aluminium, to agree with the "ium" ending of most of the other elements. In the U.S., in 1925, the American Chemical Society officially reverted to the original Davy spelling of aluminum, which is the normal spelling in the U.S..)

Friedrich Wöhler later improved on Ørsted's process by reacting aluminum chloride vapor with molten potassium instead of the potassium amalgam of Ørsted. This produced larger globules of aluminum. "Larger" is a relative term, however, as his globules still weighed only 10–15 milligrams, about as large as pin heads.

Later, in 1854, Henri Saint-Claire Deville, a French school teacher, experimented with recently-improved electrochemical cells to produce a bit of aluminum, but he realized the zinc electrodes needed for the reaction were too expensive to ever be commercially feasible. So he returned to Wohler's method using the heating of aluminum chloride. Substituting less expensive sodium in place of the potassium, he was able to produce marble-sized globules, which he re-melted into a small bar of aluminum. This piece was exhibited next to the Crown Jewels at the Paris Exposition in 1855. Deville's method was seen as an acceptable way to produce aluminum, which effectively stopped research into aluminum production by electrolysis.

Deville's work was sponsored by Napoleon III, who hoped aluminum could be used to make armor lighter in weight than existing metals of the time. This is the same Napoleon who used aluminum cutlery for prominent nobility at special social events (while the less noble attendees used the old silver or gold utensils). Napoleon also had a rattle made of aluminum for his young son. In 1852, prior to Deville's method of aluminum production, an ounce of aluminum cost $34, while an ounce of gold cost only $21.
(http://www.alcoa.com/global/en/about_alcoa/time_machine/time_machine.asp

and http://www.onlygold.com/TutorialPages/prices200yrsfs.htm) By 1859, due to increased production, the price of aluminum had dropped to $17/pound, about the same price as silver.

Although Deville's discovery worked adequately to produce aluminum from the more active metals, those metals were themselves produced from electrolysis, so this was an expensive process. Aluminum chloride was also prepared from natural aluminum-containing compounds, and it is difficult to handle as well, as it is volatile and hygroscopic, both of which interfere with the production of aluminum. Despite these drawbacks, Deville was eventually (by 1869) able to produce two tons of aluminum per year, eventually increasing that, with technological advances, to four tons annually (1884). As a result of the limited availability of aluminum by this process, the metal was very rare and therefore very expensive.

In 1884 when the Washington Monument was completed, it was capped with a 6-pound (actually, a 100-ounce) solid pyramid of aluminum. The aluminum cap was placed atop the monument as a lightning rod, of sorts. The architects chose aluminum because it was the most technologically advanced metal at the time, and it was known not to rust, so it would remain shiny and would not stain the sides of the monument with corrosion.

The cap was the largest piece of aluminum molded at that time. It was manufactured and installed for $225 ($150 over budget). An ounce of aluminum in 1884 had dropped in price to about $1.00, roughly the same as the wages for a typical worker on the monument's construction. So, it was still rather expensive at that time. The price had dropped for two reasons: it was being produced at a slightly higher rate (a few tons worldwide, rather than a few pounds), resulting in a bit of a stockpile, and no uses had yet been discovered for the new metal.

To establish its purpose as a lightning rod, construction workers attached the aluminum cap to a copper rod that went through the top stone and attached firmly to the hollow iron columns that ran the length of the monument as supports for the elevator. Copper rods that were connected to a water well below the foundation were attached to the iron columns to complete the system. Lightning struck the monument in 1885, within six months of its completion, and workers discovered damage to the stone in the pyramidion at the top of the monument. Apparently, using that aluminum cap as a lightning rod was not sufficient. Within the year, a new system was devised and installed. The cap remained, but it was surrounded by real lightning rods made of gold-plated copper rods shaped to a point at the tips. The cap was surrounded by eight of these rods, all attached to a gold-plated sheet of copper in a band surrounding the top of the monument. This band was itself attached to copper rods which joined the aforementioned hollow iron columns running the entire length of the monument within the elevator shaft. This system apparently has been successful in conducting lightning to the ground without damage to the structure.
(*JOM*, http://www.tms.org/pubs/journals/JOM/9511/Binczewski-9511.html)

Deville's method of producing aluminum through the heating of aluminum chloride and sodium had not changed much in the time period 1854-1884. It was recognized that electrolysis was capable of producing aluminum, but the electrodes were costly, and there was a need for a great deal of electricity to power the reaction. As electrical technology had progressed during this time period to produce dynamos that could provide the power needed, attention returned to electrolysis.

Charles Hall and Alcoa

Charles Martin Hall graduated from Oberlin College in 1885 and a year later, at the age of 23, he had discovered the electrolytic process to produce aluminum. Legend has it that he had been spurred on to do his research by a chemistry professor at Oberlin, Frank Jewitt, who allegedly had told his classes that “any person who discovers a process by which aluminum can be made on a commercial scale will bless humanity and make a fortune for himself." Hall apparently listened, as he succeeded and filed a patent (#400,655) for the process on July 9, 1886.

Hall’s process involved the electrolytic reduction of alumina, an electricity-intensive process. After several somewhat unsuccessful joint ventures with other entrepreneurs to commercialize the process, he finally found financial backers and formed the Pittsburgh Reduction Company, which eventually became the Aluminum Company of America, eventually changing its name to Alcoa. The new process of smelting aluminum used resistive heating, which required large amounts of newly-available electricity from huge generating plants. Hall and Alcoa sought cheaper electricity and created a major plant in Niagara, New York to take advantage of the hydroelectric plants recently built there.

The Hall process of smelting aluminum brought Hall enormous wealth. He endowed Oberlin College, his alma mater, with almost $15 million, which in those days was a huge amount.

Paul Héroult

Paul Louis-Toussaint Héroult discovered the electrolytic reduction process for aluminum in 1886, the same year as Charles Hall’s discovery. He, too, was 23 years old, as was Hall. Héroult filed for a patent on April 23, 1886 for his discovery, more than two months before Hall filed for his patent (July 9, 1886). A court trial ensued to determine to whom the patent should be awarded and Hall was able to offer proof to the court that his actual laboratory discovery preceded that of Héroult, due in no small part to Hall’s sister Julia’s impeccable notes of the experiments the Halls performed. Thus, the patent in the U.S. was granted to Hall.

Héroult did not fit the picture of the bookworm scientist who spends all his waking hours in his laboratory. Instead, Héroult’s inventions (and there were many) came to him suddenly, often while he was doing other, more social things that he loved. (This might be enlightening to students who are inquisitive and creative but don’t envision themselves working in a lab “24/7”.

More on the history of aluminum extraction from ore—U.S.

Bauxite ore was mined in the U.S., beginning in the early 1890s. The town of Bauxite, AR, located in Saline County, was the site of the first mining operations to extract alumina in the U.S.. The mining company responsible for the operation was General Bauxite Company, until 1905, when Pittsburgh Reduction Company purchased large areas of land in Saline County and the General Bauxite Company. Pittsburgh Reduction Company later incorporated (1907) as the Aluminum Company of America (ALCOA).

Ore production increased rapidly to 200,000 tons in 1914 during World War I as the need for aluminum escalated. By 1918, as the war ended, production had reached more than 550,000 tons. Production thereafter waned with decreased demand and the expansion of foreign sources in South America. But demand increased once again, along with production, with the outbreak of WWII.

In the years between WWI and WWII, the U.S. had vastly increased imports of high-grade bauxite from the Caribbean islands, but with German U-boats patrolling the Atlantic, freighters carrying bauxite were routinely sunk and bauxite imports ground to a halt. At the request of the federal government, Alcoa increased production at Bauxite with round-the-clock processing using three shifts of workers. The result of this expansion was the production of 6 million tons of ore in 1943. Production at Bauxite declined dramatically by war's end. Both Reynolds and Alcoa had operations in the Bauxite area, but Reynolds closed their plant in 1981. Alcoa continues to operate a chemical processing plant just outside Bauxite (using imported bauxite), and a few independent companies still mine small amounts of bauxite in Saline County.

The town of Bauxite was a "company town", with buildings and services provided by Alcoa. In 1969 Alcoa stopped supporting the town, although it continued to extract bauxite (at reduced capacity). Bauxite finally incorporated as an independent entity in 1973, and is growing slowly (487 residents, according to 2010 census) as urban dwellers leave Little Rock to inhabit nearby suburbs, including Bauxite.

More on the history of aluminum recycling

Aluminum was recycled very early in the metal's history. Scientists and engineers recognized that it was very difficult to produce aluminum from bauxite, so whenever aluminum scraps were left over, they were usually returned to the manufacturer or fabricator for reprocessing. But given that aluminum had limited usefulness in its early days, due to higher costs of production and thus little participation by industry in the use of aluminum to make useful items for consumers, there was little production and therefore little recycling.

With the Hall-Héroult process, the price of aluminum dropped substantially, from $12 a pound at the beginning of their process to about $0.75 per pound after Alcoa moved to Niagara Falls and benefited from the cheap electricity available there. Cheaper raw material brought increased interest in the use of aluminum as a viable starting material for many industries, resulting in new uses for aluminum being discovered every day. And with the use of aluminum in the war effort, to build lighter airplanes, etc., demand increased—as did waste. Thus recycling increased during the war years.

But it was the advent of the aluminum beverage can in the 1960s that caused recycling of aluminum to burgeon. Aluminum had finally found a home in the consumer world, and it was consumers who pushed the recycling industry.

It's been said (albeit by aluminum manufacturers) that "75% of all aluminium produced since the 1880s is still in use" today. This attests to aluminum's "infinite recyclability".

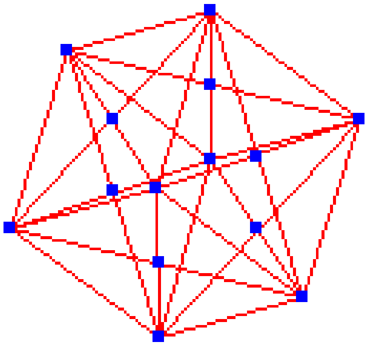
More on aluminum the metal

Important properties of the element include:

Classification: metal
Appearance: soft, silvery-gray metallic
Phase at room temp.: solid
Atomic number: 13
Electron configuration: [Ne] $3s^2\ 3p^1$
Oxidation State: **+3**, +2, +1
Pauling Electronegativity: 1.61
Electron affinity: 44 kJ/mol
Atomic mass: 26.9815 g/mol
Melting point: 660.32 °C (933.47 K or 1220.58 °F)
Boiling point: 2519 °C (2792 K or 4566 °F)
Density: 2.6989 g/cm^3
Flammability: not flammable, except as dust or fine turnings
Molar volume: 10.0 cm^3/mol
Specific heat: 0.897 J/g-^{o}C
Molar heat capacity: 24.20 J/mol-K
Heat of fusion: 10.71 kJ/mol
Heat of vaporization: 294.0 kJ/mol

Ionization energies:
- 1st—577.2 kJ/mol
- 2nd—1816.6 kJ/mol
- 3rd—2744.6 kJ/mol
- 4th—11,575 kJ/mol

Atomic radius: 143 pm
Covalent radius: 121 ± 4 pm
Ionic radius: 51 pm (Al^{3+})
Lattice structure: face-centered cube



More on bauxite

Bauxite is the principal source of aluminum, named after Les Baux, France, the site where the ore was first recognized to contain aluminum. This ore of aluminum is not itself a mineral, as it comprises gibbsite [$Al(OH)_3$], boehmite [γ-AlO(OH)] and diaspore [α-AlO(OH)], along with goethite and hematite (iron oxides), and kaolinite (a clay), and smaller amounts of anastase, TiO_2.

> Bauxite occurs in three main forms depending on both the number of molecules of water of hydration and the crystalline structure. The three structural forms of bauxite are Gibbsite, Böhmite and Diaspore.
>
> Gibbsite is a true aluminium hydroxide and Böhmite and Diaspore are both aluminium-oxide-hydroxides. The main difference between the latter two is that Diaspore has a different crystalline structure to Böhmite, and requires even higher temperatures for rapid dehydration. As can be seen from the table below Gibbsite exists in trihydrate form and the latter two are monohydrate.

	Unit	**Gibbsite**	**Böhmite**	**Diaspore**
Composition		Al(OH)3	AlO(OH)	AlO(OH)
Maximum Alumina Content	%	65.4	85.0	85.0
Crystal System		Monoclinic	Orthorhombic	Orthorhombic
Density	gcm^{-3}	2.42	3.01	3.44
Temp. for Rapid Dehydration	°C	150	350	450

> Of the bauxite ores currently being mined the dominant form is Gibbsite, followed by a mixed ore of Gibbsite and Böhmite. Differences in ore composition influence their subsequent processing. Processing conditions are also affected by impurities, chiefly compounds of iron, silicon and titanium
>
> (IAI, the International Aluminum Institute, Web site: http://www.world-aluminium.org/About+Aluminium/Production/Bauxite+mining/Geology+of+Bauxite)

There are two main types of bauxite: lateritic (silicate) bauxite and karst (carbonate) bauxite ores. Lateritic bauxites are usually found in tropical areas, where weathering conditions and good drainage allow the clay (kaolinite) to dissolve and the gibbsite to precipitate. The carbonate bauxites occur above carbonate rocks, like limestone and dolomite. Predominant locations for these deposits are in Jamaica and Europe.

Bauxite is usually strip mined, since it is usually found near the land's surface, with little or no overburden. Existing overburden frequently comprises a ferruginous (rust-colored) surface layer. In the processing of bauxite to alumina, impurities consisting of iron and titanium are removed.

More on sources of bauxite

Within the U.S.

The United States has only very limited resources of bauxite, one area located in a belt approximately 60 miles long which extends from northwestern Georgia into northwestern Alabama, and the other in Bauxite, Arkansas, near Little Rock. Although bauxite was once mined extensively (see “More on history of aluminum extraction from ore”, above) in Bauxite, Arkansas (hence the name), the reserves remaining there are insignificant, relative to world reserves.

Outside the U.S.

The United States Geological Survey (the USGS) “General Commodities Summaries” shows that in 2011 the United States imported 100% of its supply of bauxite and alumina. We imported 41% of our bauxite from Jamaica, 21% from Guinea, 18% from Brazil, 8% from Guyana and 12% from other countries.

The major producer of bauxite worldwide is Australia, with almost one-third of the world's production. Next in line are China, Brazil, Guinea and India. Bauxite is plentiful on Earth; existing reserves are projected to be sufficient to meet worldwide demand for centuries. Of greater importance in the continued production of aluminum is the electrical demand involved in the processing of alumina.

More on oxidation-reduction and electrolysis of alumina

A brief refresher on the process of oxidation-reduction is provided in another section of this Teacher's Guide, the section dealing with bioremediation:

> You may or may not have covered oxidation and reduction when you have your students read this article. Most texts have several chapters on this topic, but a simple review of major ideas is in order. Generally

> oxidation-reduction reactions are any chemical reactions in which atoms change their oxidation number. The reactions may be simple ones, like $C + O_2 \rightarrow CO_2$, in which oxygen is oxidized and carbon is reduced. Or the reactions may be more complex like the oxidation of glucose in the body via a series of electron transfers to produce carbon dioxide and water.
>
> Oxidation is defined as loss of electrons and reduction is defined as gain of electrons. If an atom loses electrons its oxidation state (or oxidation number) becomes more positive and if an atom takes on electrons its oxidation state (number) becomes more negative. Oxidation and reduction always occur together in order to conserve electrons. We say that the overall oxidation-reduction reaction occurs in two half reactions, one describing the oxidation part of the overall reaction and the other describing reduction.
>
> In an oxidation-reduction reaction the substance that removes electrons from other substances is said to be the oxidizing agent. And because it accepts electrons, it is reduced. Of course, the reverse is also true. The substance from which electrons are removed is called the reducing agent, and it is itself oxidized.

In the recycling of aluminum article, the smelting process involves electrolysis, which is an oxidation-reduction reaction. The entire reaction involves both an oxidation reaction and a reduction reaction.

As described in the article, the alumina is mixed with cryolite and heated, resulting in their reacting according to equation 1 below.

(1) $Al_2O_3 + 4\,[AlF_6]^{3-} \rightarrow 3\,[Al_2OF_6]^{2-} + 6\,F^-$

The reduction half-reaction involves the production of aluminum and occurs at the cathode, according to equation 2 below.

(2) $[AlF_6]^{3-} + 3\,e^- \rightarrow Al + 6\,F^-$

The oxidation half-reaction involves the addition of oxygen to the carbon atom in equation 3 below.

(3) $C + 2\,[Al_2OF_6]^{2-} + 12\,F^- \rightarrow CO_2 + 4\,[AlF_6]^{3-} + 4\,e^-$

To obtain the overall redox reaction, you must add the three equations above so that both mass and charge are conserved. Thus you need 2 of equation (1), 4 of equation (2), and 3 of equation (3).

$$\begin{array}{l}
2\,Al_2O_3 + \cancel{8\,[AlF_6]^{3-}} \rightarrow \cancel{6\,[Al_2OF_6]^{2-}} + \cancel{12\,F^-} \\
\cancel{4\,[AlF_6]^{3-}} + \cancel{12\,e^-} \rightarrow 4\,Al + \cancel{24\,F^-} \\
3\,C + \cancel{6\,[Al_2OF_6]^{2-}} + \cancel{36\,F^-} \rightarrow 3\,CO_2 + \cancel{12\,[AlF_6]^{3-}} + \cancel{12\,e^-} \\
\hline
2\,Al_2O_3 + 3\,C \rightarrow 4\,Al + 3\,CO_2
\end{array}$$

More on melting points and impurities

The component substances of the mixture from which aluminum is extracted electrolytically in the Hall-Héroult process are shown in the table below, along with their formulas and melting temperatures.

Substance	Formula	Melting Temperature (^oC)
Alumina	Al_2O_3	2072
Cryolite	Na_3AlF_6	1012
Fluorspar, fluorite	CaF_2	1360
Aluminum fluoride	AlF_3	1291

As you can see, the melting temperatures of all the components are greater than 1000 ^oC. Yet when all four of these are mixed together and heated in the commercial electrochemical cells, or pots, the mixture can be kept in a molten state for electrolysis at temperatures in the 920–980 ^oC range, lower than any of the components. The fluorspar and aluminum fluoride act as impurities and lower the melting temperature of the cryolite (and vice versa), thus bringing the mixture's melt temperature down below any of the substances.

Alumina, however, is not an impurity in the same sense as the other two. While alumina is insoluble in water, it is highly soluble in the liquid (molten) mixture of cryolite, fluorspar and aluminum fluoride. Thus the cryolite-fluorspar-aluminum fluoride mixture acts as a good solvent for alumina, and the mixture will remain liquid (molten) at relatively low temperatures.

The alumina, dissolved in the other ionic substances, exists as ions (as do the other substances), and the whole mixture conducts electricity, a requirement for electrolysis. And while pure alumina could be melted directly and would conduct in its molten state alone, a temperature exceeding 2000 ^oC (its melting point) would be needed for this process. The energy required for this process would be excessive, compared to that needed for the Hall-Héroult process.

More on red mud

The method used commercially to produce aluminum involves chemically extracting alumina from bauxite using sodium hydroxide. But since the alumina content of bauxite ranges from 45-60%, impurities comprise about one-half of the source bauxite. Much of that is composed of iron compounds, which impart the red color to the "residue" produce in the alumina extraction process. (Alumina is white.) This residue also contains the other impurities from the bauxite; e.g., silicon, titanium and possibly trace amounts of heavy metals, a significant amount of unextracted alumina and, finally and significantly, the remaining sodium hydroxide that was not used up in the dissolving of alumina in the extraction process. This caustic compound imparts a high pH (as high as pH-13) to the remaining mix. The high pH is a problem for disposal, so typically the waste is simply stored as a slurry in huge holding ponds, until the water solvent evaporates. The volume of red mud produced can vary from one to two times the amount of alumina produced. More than 70 million tons of red mud are produced worldwide annually, so storage of such huge quantities of waste becomes a huge problem. (Some alumina-producing plants close to shorelines (Germany and France, for instance) have actually dumped their red mud into the ocean, although dead zones (areas of no aquatic life) are found in the centers of these dump sites, and hence this process is becoming less and less desirable.

The problem of storage these huge quantities of red mud became critical in Hungary on October 4, 2010, when a very large reservoir filled with the red mud ruptured, releasing almost one million m^3 of the caustic material to flow out over the landscape. The 1–2 meter-high tsunami of mud flooded nearby towns, killed many farm animals and at least four people, caused chemical burns on 120 more, and left the countryside covered with the red muck. The alkaline mess covered the land, effectively killing all vegetation in the area. You can see full-screen-size photos of the devastation at the *Boston Globe* Web site, Boston.com, http://www.boston.com/bigpicture/2010/10/a_flood_of_toxic_sludge.html.

“According to a press release by MAL, the mud had the following chemical percentage make-up (this expresses the amounts of different elements, not necessarily the actual solids):”

Metal oxide	**Percentage**	**Notes**
Fe_2O_3 (iron(III) oxide)	40–45 %	Gives the red colour of the mud
Al_2O_3 (aluminium oxide)	10–15 %	Unextracted aluminium oxide
SiO_2 (silicon dioxide)	10–15 %	Present as sodium- or calcium-alumino-silicate
CaO (calcium oxide)	6–10 %	See also portlandite
TiO_2 (titanium dioxide)	4–5 %	Impurity present in bauxite
Na_2O (bound sodium oxide)	5–6 %	Responsible for the highly (alkaline) pH and the chemical burns

(http://en.wikipedia.org/wiki/Ajka_alumina_plant_accident)

Unlike many other mine waste products, red mud does not typically ontain high levels of heavy metals (but still about seven times normal soil levels), nor is it especially radioactive.

To avoid potential disasters like this flood, scientists are investigating ways to minimize the volume of waste. Simple procedures, like heating the waste to drive off more moisture results in smaller volumes of waste that go into holding ponds, and this reduces the amount of land needed for these ponds. But this still doesn’t eliminate the waste, or make it into useful products.

> Many attempts have been made to find environmentally safe methods of disposing or using red mud. Thakur and Sant, as cited by Hulya and Jens (2002) and Tsakiridis et al. (2002) have listed a number of uses for this waste, such as absorbents to remove H2S from industrial emissions; constituents in building materials such as bricks, ceramics, cement, concrete, and road materials’ coagulants to remove phosphate in wastewater treatment; catalysts in coal hydrogenation or in the preparation of anticorrosive materials and pigments particularly for use in marine environments.
>
> More recently, red mud has been used in columns to remove bacteria and viruses from secondary effluents (Tsakiridis et al., 2002); as a pH modifier in heap leaching of gold bearing ores and as a neutralizing agent for acid wastes such as those obtained from the production of gypsum or titanium dioxide. All these processes can utilize only a small fraction of the total amount of red mud produced (Hulya & Jens, 2002).

(Ghorbani, Y., Oliazadeh, M., Shahvedi, A. Aluminum Solubilization from Red Mud by Some Indigenous Fungi in Iran. *Journal of Applied Biosciences* **2008** *7*, pp 207–213. http://www.biosciences.elewa.org/JABS/2008/7/3.pdf)

Research is being done to extract more alumina from red mud (from the 10-15% left unextracted). Scientists in Iran, for example, have found that some indigenous fungi can solubilize the alumina in red mud and that heating the mud increases the bioleaching process. It was also found that the fungi did not solubilize the iron(III) oxide, meaning that the separation of alumina from the rest of the mud was enhanced by this process. This method could reduce the volume of red mud waste, while also improving the yield of alumina extraction. (See reference above.)

Another company, Virotec, has developed a process using seawater to neutralize the pH of the red mud, requiring up to 20 times the volume of sea water, but this process is too expensive, so they use only 5 times the volume of sea water compared to the red mud. This results in a pH of about 9.0–9.5. The addition of a small amount of acid to the end-product produces material that meets discharge standards.

The product is still alkaline, so it has the capability of neutralizing other materials. Thus it is being used to neutralize mine tailings from other metal extraction processes.

It also has a “very high trace metal trapping capacity (greater than 1,000 milliequivalents of metal per kg)” and can be used in conjunction with existing technology to extract trace metals from mining operations. Their product also is a good flocculent and it traps and binds phosphate, both of which could find application in the sewage treatment industry.
(source: http://www.azom.com/article.aspx?ArticleID=2071)

More on facts about recycling aluminum

Like almost all other counties in all the states of the U.S., Washington County, Oregon recycles much residential waste, including aluminum. Here is information gathered from their Web site:

Local Recycling Process for Aluminum

- Collected and hauled to a processor
- Cleaned and sorted and sold to scrap metal dealer
- Shredded, melted, and cast into ingots (in some cases sold in molten form)
- Sold domestically or overseas
- Ingots are purchased by manufacturers who roll, form, or extrude the metal into a finished product.

Resources Used to Make 1 lb. of Aluminum from Bauxite:

First Stage - Alumina Plant
4 pounds of bauxite
1/2 pound of coal
1/4 pound fuel oil
1/2 pound soda

1/8 pound lime

Result: 2 pounds of alumina

Second Stage - Reduction Plant
2 pounds alumina
1/2 pound coke/ pitch
dash of cryolite, fluorspar, and aluminum fluoride

End result: 1 pound aluminum

- Approximate energy needed to make 1 lb. aluminum from virgin material: 8 kilowatt hrs (27,276 BTUs)

- Approximate energy needed to make 1 lb. aluminum from recycled material: 0.4 kilowatt hrs (1,364 BTUs)

("ReportWriters Tech Sheet on Aluminum", Washington County, Oregon Cooperative Recycling Program—obtained 2002, no longer available online)

More on recycling aluminum

(Earth911.com, http://earth911.com/news/2011/10/19/united-states-waste-in-numbers-then-and-now/)

2008 Recycling data for aluminum in U.S. municipal solid waste (MSW) streams:

	Generation	Recovery		Discards
Product Category	**(Thousand tons)**	**(Thousand tons)**	**(Percent of generation)**	**(Thousand tons)**
Aluminum				
Beer and Soft Drink Cans	1,390	670	48.2%	720
Food and Other Cans	70	10	14.3%	60
Foil and Closures	420	40	9.5%	380
Total Aluminum Packaging	1,880	720	38.3%	1,160

(“Municipal Solid Waste Generation, Recycling, and Disposal in the United States Tables and Figures for 2008”, U.S. EPA, Office of Resource Conservation and Recovery, November 2009; http://www.epa.gov/osw/nonhaz/municipal/pubs/msw2008data.pdf)

2010 Recycling data for aluminum in U.S. municipal solid waste streams:

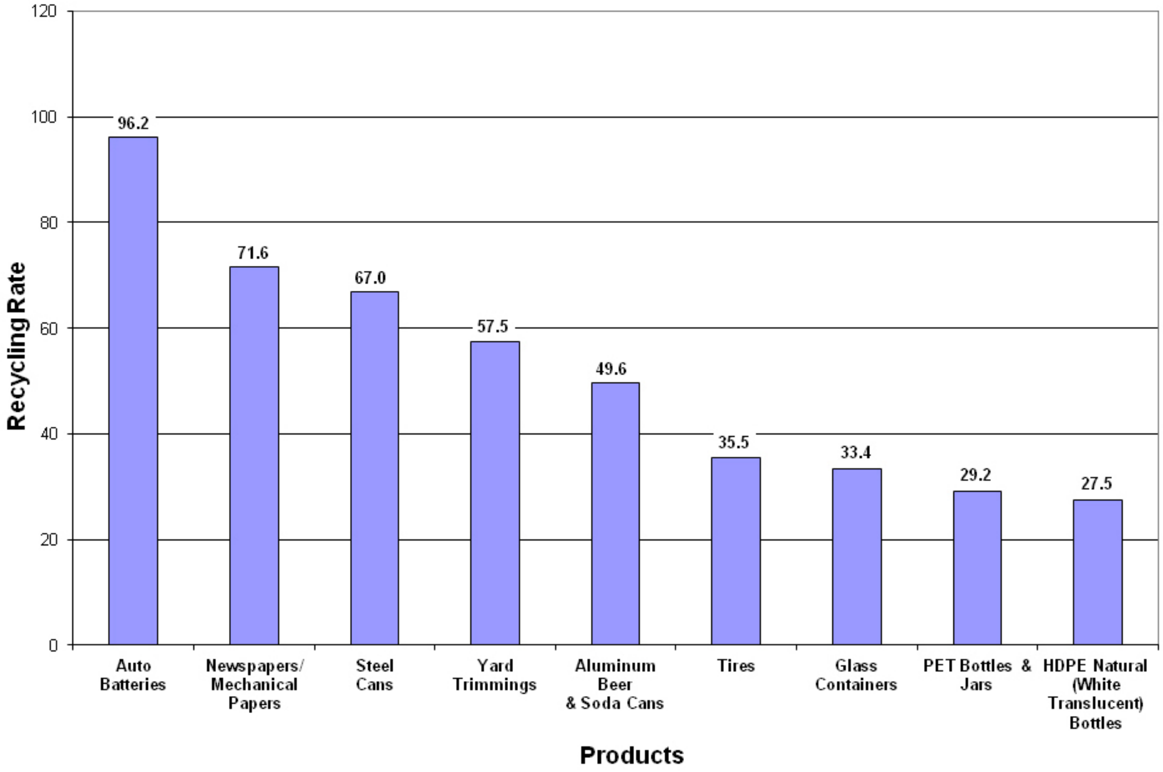
Product Category	Generation	Recovery		Discards
	(Thousand tons)	(Thousand tons)	(Percent of generation)	(Thousand tons)
Aluminum				
Beer and Soft Drink Cans	1,370	680	49.6%	690
Food and Other Cans	70	NA		70
Foil and Closures	460	NA		460
Total Aluminum Packaging	1,900	680	35.8%	1,220

(“Municipal Solid Waste Generation, Recycling, and Disposal in the United States Tables and Figures for 2010”, U.S. EPA, Office of Resource Conservation and Recovery, December 2011; http://www.epa.gov/epawaste/nonhaz/municipal/pubs/2010_MSW_Tables_and_Figures_508.pdf)

As you can see from the data above, the amount of aluminum recovered from the MSW stream has increased slightly for soft drink cans, while the amount generated has decreased slightly. This resulted in an increase in the percentage of recovery increasing from 48.2% to 49.6% for soft drink cans (and a decrease from 54.6% in 2000). Unfortunately, this gain for recycling aluminum from cans is offset by an increase in generation in the “Foil and Closures” category, with a fairly significant decrease in the amount of aluminum recovered from both non-“Beer and Soft Drink Cans” categories. This has resulted in 60,000 tons more aluminum discarded in landfills, and an overall decrease in the percentage of aluminum recycled. Still, the 35.8% recovery rate for 2010 is a significant improvement over the 27.4% figure noted in this same report for the year 2000.

The chart below shows a comparison of the rate of aluminum recycling vs. that of other categories of municipal waste. Aluminum is recycled at a greater rate than its competitor drink containers, glass and PET bottles.

Figure 3. Recycling Rates of Selected Products, 2010*



(http://www.epa.gov/epawaste/nonhaz/municipal/index.htm)

While the data above show the recycling of aluminum from beer and soda cans and other packaging—and this seems to reflect well on the aluminum industry, there is still a very significant amount of aluminum that enters landfills from other sources; e.g., appliances, furniture and miscellaneous durable products. In 2010, these sources accounted for approximately 1.3 million tons of aluminum being dumped in landfills, compared to the 1.2 million tons discarded from aluminum packaging. And almost none of this metal was recycled or recovered. It looks like we still have a long way to go.

Number of 12-ounce Soft Drink Cans Made per Pound of Aluminum, by Year
1975- 23.00
1980- 24.24
1985- 26.60
1986- 27.00
1987- 27.40
1988- 28.25
1989- 28.30
1990- 28.43
1991- 28.87
1992- 29.29
1993- 29.51
1994- 30.13
1995- 31.07
1996- 31.92
1997- 32.57
1998- 33.04
1999- 33.10
2000- 33.12
2001- 33.40
2002- 33.79
2003- 33.72
2004- 33.92
2005- 34.01
2006- 34.21
2007- 34.17
2008- 34.18

“Recycling just 1 ton of aluminum cans conserves more than 207 million Btu, the equivalent of 36 barrels of oil, or 1,665 gallons of gasoline.” EPA 2010 report.

“In 1972, 1 pound of aluminum cans was equivalent to about 22 empty cans. Due to advanced technology using less material and increasing the durability of aluminum cans, as of 2002, 1 pound of aluminum cans is equivalent to about 34 empty cans.”

(http://earth911.com/recycling/metal/aluminum-can/facts-about-aluminum-recycling/)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Heat of fusion—**Aluminum melts at 660 ^{o}C. The heat needed to melt aluminum, its heat of fusion, is 10.8 kJ/mol. (Compare to water’s heat of fusion: 6.02 kJ/mol, or that of gold: 12.55 kJ/mol.) (Water melts at 0 ^{o}C and gold at 1064 ^{o}C.)
2. **Melting points and the effect of impurities—**Aluminum oxide melts at a much lower temperature in a mixture of cryolite and fluorspar than it does in its pure state—a prime example of the effect of an impurity on the melting point of a pure substance.
3. **Electrolysis—**Aluminum is extracted from alumina by the process of electrolysis. This is a great example of electrolysis to use in the classroom.
4. **Oxidation-reduction—**Electrolysis is really oxidation-reduction. As the article states, aluminum metal is produced at the cathode, where reduction takes place, and carbon dioxide is produced at the anode, where oxidation occurs.
5. **Corrosion—**Aluminum is resistant to corrosion, or oxidation-reduction, due at least in part to the oxide coating that forms on its surface as it reacts with oxygen from the air.
6. **Chemical history—**Knowing the history of the discovery and production of aluminum may help to make chemistry more interesting and “real” to students—especially when two young men (only 23 years old)—Charles Hall and Paul Héroult—discovered the same process, which made both of them millions of dollars.
7. **Smelting—**The science behind smelting usually involves both melting (phase changes) and oxidation-reduction processes to reduce a metal from its ore. In many cases, the ore is the metal oxide, and carbon can be used to reduce the metal from its oxide. In the case of aluminum the ore isn’t really melted, so much as it is dissolved, in molten cryolite, aluminum fluoride.
8. **Recycling / sustainability / “green” chemistry—**Recycling is one small part of green chemistry or sustainability. In the chemical industry green chemistry it means doing chemistry safer—starting with less hazardous materials using less hazardous processes that produce less hazardous waste—throughout the manufacturing of a specific material. For more information on green chemistry, see “Twelve Principles of Green Chemistry at this EPA Web site, http://www.epa.gov/sciencematters/june2011/principles.htm, or visit the American Chemical Green Chemistry Institute Web site at http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_TRANSITIONMAIN&node_id=830&use_sec=false&sec_url_var=region1&__uuid=6dc0fba5-ede7-4b9c-a3a6-b4e3a761e167.
9. **Chemistry in the news—**Red mud has been in the news in recent years as the walls of the huge reservoirs of the sludge (“red mud”) left over from aluminum processing were breached and the millions of gallons of red mud polluted nearby cities and rivers. These news events may not paint a pretty picture of chemistry, but they keep chemistry in the news, and they may inspire chemistry students to enter the profession for the sole reason of ameliorating these environmental problems.
10. **Sources of raw materials/ Ores—**Bauxite is the ore from which alumina is purified, and then aluminum is extracted. Its primary source for the U.S. is Jamaica

11. **Jobs in the chemical industry—**Students don't often see job possibilities in the field of chemistry and, although recycling in India may not be an inviting job prospect, you can use it to show students that chemistry is involved in many and varied job opportunities.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"It should be easy to set up small-scale, individual recycling centers here in the U.S., just like those in India."** *Actually, there are many reasons why this isn't being done in the U.S. today. See Anticipating Student Questions #1, below.*
2. **"There is really no good reason for me to recycle my aluminum soda cans, so I just throw them away."** *As shown in the article, there are many benefits to recycling aluminum cans, including energy, material and monetary concerns; and as we all know, any successful recycling program begins with and depends on the individual—**you**. Besides, as we all also know, there is no "away". The discarded cans go into landfills, which are filling up all too quickly.*
3. **"Since aluminum remains shiny, it must not corrode."** *In fact, aluminum is very reactive and corrodes easily; however, when the surface of aluminum reacts with oxygen from the air, a thin (0.01 μ, 0.00001 mm), transparent layer of the compound aluminum oxide immediately forms, making a very tight covering on the surface. This surface covering protects the rest of the metal underneath from coming in contact with oxygen from the air, thus preventing further corrosion.*

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

1. **"With so many people here in the United States out of work right now, why don't more people <u>here</u> do recycling to make money, like they do in India?** Many *reasons prevent individuals here from recycling. Here are a few:*
   a. *It is not a socially-accepted "occupation", meaning that anyone participating in this endeavor would probably be "looked down upon".*
   b. *Recycling in the U.S. is mostly a large-scale industry. There is no mechanism established in the U.S. by which individuals can be their own recyclers.*
   c. *Individuals recycling scrap materials create a lot of waste. Environmental laws on the books in the U.S. do not allow for the accumulation of all these wastes that would ensue from individuals recycling materials. The waste includes solids, liquids and gases produced in the chemical reactions, as described in the article.*
   d. *The cost of living in the U.S. is much higher than in India, so that an individual here would have to recycle far more material in order to reap the same rewards of daily living than would a person in India.*
   e. *As you can tell from reading the article, recycling by an individual is an arduous task done for little reward.*
   f. *There exist in the U.S. safeguards like unemployment compensation, paid for by the government, which can provide subsistence living for unemployed people until they are able to get back into the workplace.*
2. **"Why does it take so much energy to extract aluminum from bauxite?"** *Alumina, the source compound for aluminum found in bauxite, is a very thermodynamically stable compound, so it is very difficult to break the bonds between the aluminum and oxygen*

atoms within the structure. It also has a very high melting point, so it is difficult to melt it in order to effect an oxidation-reduction reaction using just alumina. (That's why cryolite is added to the alumina, to reduce the mixture's melting point.

3. **"Why does the author say, 'Electrolysis can be performed only on a liquid'?"** *In order for electrolysis to occur, ions must be able to move through the substance toward (and to) the electrodes to carry the charge throughout the system. This can only happen in a liquid—either a solution or a molten substance. In solids the material is held rigidly in place and no ions can move through the substance, and in a gas the particles are too far apart to feel the effect of charges and subsequently move toward the electrodes.*
4. **"Are all electrolysis reactions also oxidation-reduction reactions?"** *Yes, electrolysis involves the addition of electrons to cations at the cathode, and the removal of electrons from the anions at the anode. As these reactions happen at the electrodes, electrons are used up in the reduction process at the cathode and released in the oxidation process at the anode. The electrons travel through the wire outside the reaction cells to complete the electrical circuit.*
   In the case of the electrolysis of alumina, the AlF_6^{3-} *ion can be thought of as the cation (even though it is negative) because the Al within the* AlF_6^{3-} *structure is very positive due to the fluoride ions attracting aluminum's electrons toward themselves. It is the* Al^{3+} *ion which is then reduced to Al atoms at the cathode. At the anode, the carbon atom appears to lose four electrons, as a lone carbon atom is attracted to two oxide (-2) ions to form* CO_2 *in an oxidation reaction.*
5. **"What happens to the iron, silicon and titanium residues from bauxite processing?"** *These residues are sometimes referred to as ferruginous materials, and they comprise the "red mud" that has been in the news recently, as holding pools of this material were breached and contaminated nearby towns and waterways in Europe.*
6. **"If smelting is an electrolysis reaction, and electrolysis is oxidation-reduction, why then don't the equations for the smelting of aluminum add up to give you the overall equation for the oxidation-reduction reaction?"** *See the "More on oxidation-reduction" section above for a detailed explanation of how to add up the equations to give you the overall equation.*
7. **"What do the aluminum-producing companies do with all the waste material from the Hall-Héroult process?"** *The waste, called red mud, is typically stored in huge holding ponds, to allow for the evaporation of water in order to minimize the volume of the waste. For more information, see "More on red mud", above.*

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

1. To demonstrate the existence of the thin, transparent (and therefore invisible) oxide coating on aluminum, you could clean some small strips of aluminum with steel wool and after cleaning, add them to a small test tube and pour in enough 1 M HCl to cover them. Observe that almost no reaction happens immediately. (No bubbles of hydrogen gas produced as the metal doesn't react with the acid, as would, for example, zinc metal). Heat the tube gently and bubbles will begin to appear as the acid reacts first with the oxide coating, exposing bare metal to the acid, and then with the metal itself. The bubbles will form more rapidly as the coating is completely worn off. Continued reaction will eventually result in a lower rate of bubble formation as the acid concentration decreases as it is used up in the reaction (acid is limiting reagent). (http://www.alkaseltzerplus.com/asp/student_experiments_3.html#ideas)
2. In a worksheet format, this pdf file, "Recycling Metals", from the Mineral Information Institute (MII) gives students information and data about the processing and recycling of aluminum in

order to answer these questions: Why is aluminum used in beverage cans, storm window and door frames, bicycles and backpacks? If the price of aluminum increases, should we still use it to make beverage cans? .Why is recycling aluminum so popular? .Why can we make more 12-ounce cans today from a pound of aluminum than we could 20 years ago? How can people help recycle metals other than aluminum? View the two-page activity at http://www.mii.org/pdfs/recycle.pdf.

3. The October 1990 *ChemMatters Classroom Guide* describes a student experiment using aluminum metal from a soft drink can to prepare alum crystals. (See the References section below for more information about obtaining the ChemMatters 25-year CD containing this and all other *ChemMatters* issues and *Teacher's Guides*.)
   Another version of this experiment, called "Alum from Waste Aluminum Cans", along with extensive background information, can be found at the chymist.com Web site: http://www.chymist.com/alum%202009.pdf.
4. Students can experiment with anodizing aluminum. This can show them the aluminum oxide coating on the aluminum surface, and how that coating can be decorated. A source of such an experiment can be found at the Terrific Science Web site. The pdf file contains both student and teacher directions: http://www.terrificscience.org/lessonpdfs/14AlAdventure.pdf. The Creative Chemistry Web site from the UK also has directions for students and teachers: http://www.creative-chemistry.org.uk/activities/anodising.htm. There is quite a bit of electrochemistry and redox going on in this reaction.
5. A student experiment describing a commercial product that uses a small block of aluminum, baking soda and hot water to remove tarnish from silver objects is found in the *ChemMatters Classroom Guide* from the December 1996 issue, available on the ChemMatters 25-year compilation CD. The guide accompanies an article from the December 1996 issue of ChemMatters called "Silver Lightning". This *JCE* article describes a similar demonstration/ experiment in which the instructor demonstrates the polishing process and then asks students to determine the possible composition of the metal block, based on the activity series of metals: http://pubs.acs.org/doi/pdfplus/10.1021/ed085p68, available to ACS member subscribers. Or you can try this site: http://scifun.chem.wisc.edu/homeexpts/TARNISH.html.
6. A great demonstration using aluminum that relates to thermodynamics is the very exothermic thermite reaction that reacts aluminum metal with iron(III) oxide to produce heat and light. A scaled-down version of the demonstration using aluminum foil and large iron/steel ball bearings can be found in the February 2002 issue of *ChemMatters*, available on the 25-year CD described in the References section below. Here's a video clip showing the reaction: http://www.youtube.com/watch?v=s4De8-B1CSk&feature=related.
7. The more classic thermite demonstration can be found here: http://www.thecatalyst.org/other/thermite/. **NOTE: This reaction is VERY exothermic, producing temperatures around 2000 ^{o}C or higher! Extreme caution must be used!**
   Another write-up for the demonstration can be found at Dave Katz's Web site, http://www.chymist.com/Thermite%20reaction.pdf. He includes a brief history of thermite's use in the past and photos of the reaction at various stages in its development.
   Video clips, which are a much safer way to go, can be found on YouTube (simply "Google" thermite videos). This is one example: http://www.youtube.com/watch?v=2jGe2ievffU&feature=related.
   This site, http://www.ilpi.com/genchem/demo/thermite/index.html#demo, describes the set-up for the reaction, shows photos and has a short video clip. It also presents a bit of follow-up for a classroom lesson to calculate ΔH for the reaction. It might be of interest to students to point out that the amount of energy produced by a typical thermite reaction demonstration approximates the amount needed to produce one 12-ounce aluminum soft drink can from bauxite.

Here's a present-day video of the use of the thermite reaction to weld railroad tracks together: http://www.youtube.com/watch?v=vCqG3rWtNbc&feature=related.

8. The amphoteric nature of aluminum can be demonstrated using aluminum sulfate, sulfuric acid and sodium hydroxide. One method can be found in the Journal of Chemical Education article "Acid-Base Chemistry of the Aluminum Ion in Aqueous Solution". (Koubek, E. *J. Chem. Educ.* **1998**, *75* (1), p 60) The article is available online to ACS-member *JCE* subscribers at http://pubs.acs.org/doi/abs/10.1021/ed075p60.1?prevSearch=Acid%25E2%2580%2593Base%2BChemistry%2Bof%2Bthe%2BAluminum%2BIon&searchHistoryKey.
9. Although it is a bit of a stretch re: the aluminum article, students can use an organic melting point determination experiment to show that the melt temperature of a mixture like alumina and cryolite is lower than the higher-melting component. This one uses the MelTemp apparatus more commonly found in college settings: http://swc2.hccs.cc.tx.us/pahlavan/2423L2.doc; this one uses Thiele tubes, more likely to be found in a high school lab: http://employees.oneonta.edu/knauerbr/chem226/226expts/226_expt01_pro.pdf.
10. As a density problem, you could pose the following question to students: "Is the aluminum cap on the top of the Washington Monument a solid object made only of aluminum?" Require them to cite the evidence for their decision, including calculations. They can start here:
    - Width of aluminum tip: 5.6 inches (14.22 cm) on each of its four sides
    - Height of aluminum tip from its base: 8.9 inches (22.61 cm)
    - Weight of aluminum tip on capstone: 100 oz (2.85 kg)
11. Let students calculate the number of cans recycled in the U.S. annually. They can use dimensional analysis and this estimate from the Can Manufacturers Institute: 105,784 cans recycled per minute in the U.S.. (I get almost 56 billion.) You could follow this up by asking how much these cans weigh. (Students can search for today's weight of one can.) They could also calculate the value of these cans, after searching for the present value per kg or per ton.
12. You can reuse soft drink cans to show the effect of reduced vapor pressure in the chapter on gas laws by heating a small amount of water in the can to boiling and then quickly inverting the can into an ice-water bath. The can will implode vigorously. See this site for a short video clip: http://www.nc-climate.ncsu.edu/education/experiments.php, or this one for a close-up and slow-motion video of the implosion.
13. "The Aluminum Can as Electrochemical Energy Source" from *J Chem Ed* describes an experiment constructing an electrochemical cell that uses aluminum strips from a soft drink can to generate sufficient voltage and amperage to drive a small motor or light an LED: http://pubs.acs.org/doi/pdfplus/10.1021/ed070p495. (subscribers only)

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

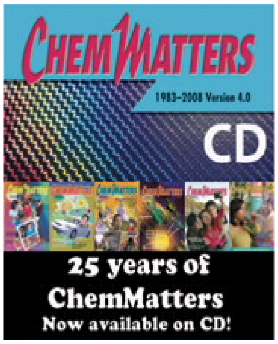
1. Low concentration of aluminum compounds in drinking water has been implicated in pin-hole pitting and leaks in household copper pipe. Students may want to pursue research in this area. They could begin here: http://pubs.acs.org/isubscribe/journals/cen/81/i33/html/8133sci1.html.
2. Students might want to do research and report to the class on red mud, the waste product formed by the Bayer process to produce aluminum. They could start here: The Red Mud Project at http://www.redmud.org/home.html. This site provides a significant number of links to work being done around the globe to utilize this waste material.

Students may become more interested in red mud after seeing its effects on nature after the red mud flood in Hungary on 10/4/10. They could begin here: http://www.boston.com/bigpicture/2010/10/a_flood_of_toxic_sludge.html or here: http://www.msnbc.msn.com/id/39513858/ns/world_news-europe/t/ecological-catastrophe-toxic-sludge-kills/. This site has two videos and almost 40 photos of the damage.

3. Students concerned about the red mud flood of Hungary may want to study how the waste from alumina processing is handled here in the U.S.. They can start here: http://www.msnbc.msn.com/id/39792631/ns/us_news-environment/t/hungary-has-toxic-sludge-us-has-red-dust/.
4. For students who appreciate mathematics as an art, you might want to direct them to this website: http://www.scribd.com/bernardpietsch/d/6378299-The-Washington-Monument-Icon-by-Design. The author details many mathematical relationships among the component parts of the Washington Monument and its design. It includes a lot of calculations involving geometry. No chemistry here (OK, maybe one discussion about density of aluminum vs. gold, but that's about it), only math. Indeed, according to the authors, "Working collaboratively with protractor, ruler, and calculator, the intellect and intuition of each student would investigate our national icon as form, metaphor and consummate demonstration of *e pluribus unum*."
5. Female students might be interested in researching the role that Charles Hall's sister Julia Brainerd Hall played in his research and discovery of aluminum. Without her assistance, the patent for the process might have gone to Héroult.
6. Students might be interested in researching the effectiveness of all the methods of managing solid in the U.S.; e.g., landfills, combustion with energy recovery, recycling, and composting. They could start with some of the EPA reports; e.g., here: http://www.epa.gov/osw/nonhaz/municipal/msw99.htm. (These reports show that, by using the other methods of waste reduction, the amount of waste dumped into landfills has remained fairly constant [with some volatility] since 1980.)

References (non-Web-based information sources)

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 Web site screen, click on the *ChemMatters* CD icon like the one shown here 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.)

Some of the more recent articles (2002 forward) referenced below may also be available online at the URL listed above. Simply click on the "Past Issues and Teacher's Guides" button at the right. If the article is available online, that will be noted.

Gimarc, B. Friedrich Wöhler's Lost Aluminum. *ChemMatters* **1990**, *8* (3), pp 14–15. The article discusses the discovery of an envelope containing several tiny pieces of aluminum with a note from Wöhler and the subsequent uncovering of the mystery behind the envelope. The author discusses a bit of the history and chemistry of aluminum.

The October 1990 *ChemMatters Classroom Guide* for the Wöhler article provides data on the properties of aluminum, and on pages 2 and 3 of the guide an experiment is described that students can do to react aluminum from a soft drink can with sulfuric acid to produce alum (aluminum sulfate) crystals.

Shaw, D. Miracle Thaw—Can It Take the Heat? *ChemMatters* **1997**, *15* (3), pp 4–6. The author discusses several physical properties of aluminum that make it useful in a device that quickly thaws frozen foods.

Tinnesand, M. Mighty Thermite—A Solid Hit! *ChemMatters* **2002**, *20* (2), pp 14–15. Author Tinnesand describes the role of the highly exothermic thermite reaction (aluminum reacting with iron(III) oxide) in history, and provides a way for you to demonstrate the thermite reaction in class.

The Teacher's Guide to the April 2002 issue of *ChemMatters* contains additional information about thermite.

Shaw, D. Silver Lightning. *ChemMatters* **1996**, *14* (4), pp 4–5. The author evaluates an infomercial product of the era that used a small slab of aluminum metal to remove tarnish from silver objects. He discusses the chemistry involved in the electrochemical reaction involving aluminum, silver, baking soda and hot water. The process involves the electromotive series of metals.

A student experiment to actually do the removal of tarnish from silver objects is found in the *ChemMatters Classroom Guide* from the December 1996 issue.

Craig, N. Charles Martin Hall: The Young Man, His Mentor, and His Metal. *Journal of Chemical Education*, **1986** *63* (7), p 557–559. The author describes Hall's work with the discovery of aluminum, from his days at Oberlin College (1880-85), through the trials he faced to prove his invention and upscale to commercial production, to his being awarded the Perkin Medal in 1911. It also discusses.

Hauserman, W. B. Thermodynamics of Resource Recycling. *Journal of Chemical Education*, **1988** *65* (12), p 1045–47. Author Hauserman discusses in great detail the various steps that need to be considered in the evaluation of a recycling process. He starts out with a general consideration but quickly moves to an evaluation of the process of recycling aluminum. He elucidates 14 steps in the process. Dated values ($) do little to detract from the message.

Web Sites for Additional Information (Web-based information sources)

More sites on aluminum

After studying aluminum, students could take a 10-question quiz on the subject from curiosity.com at http://curiosity.discovery.com/topic/metals/aluminum-quiz.htm.

The WebElements Web page contains a section on the properties of aluminum, as well as a history of the element: http://www.webelements.com/aluminium/history.html.

The History Channel's "Modern Marvels" television program sells a 45-minute video on aluminum. You can purchase the DVD online here: http://shop.history.com/modern-marvels-aluminum-dvd/detail.php?p=70105#top. At the time of the writing of this Teacher's Guide, the price was $20.99. The video discusses the making of aluminum foil and its history as a candy and cigarette-packaging material prior to its use as a food wrap and its bauxite ore source and alumina processing, including the chemical reactions occurring in the industry. It has a nice history of the discovery of aluminum also. Airplanes, cars and aluminum bats are all profiled, as well as the use of aluminum in space exploration and aluminum foam in building structures. YouTube also has the same video (free) at http://www.youtube.com/watch?v=yqxaVkyVbY4.

Aluminum can be reinforced with boron, silicon carbide or graphite to increase its strength. More information can be found in this August 30, 2004 cover-story article, "Composite Materials", from *Chemical and Engineering News* (*C&E News*): http://pubs.acs.org/isubscribe/journals/cen/82/i35/html/8235composites.html.

A November 30, 2009 *C&E News* article, "For Ignition, Mix Metal and Ice" describes the use of nano-particles of aluminum mixed with ice to form a (not-ready-for-prime-time) rocket propellant: http://pubs.acs.org/isubscribe/journals/cen/87/i48/html/8748sci2.html.

This page from the "rocksandminerals.com" Web site, although somewhat dated (1999), provides a good description, with illustrations, of the various steps in the processing of aluminum: http://www.rocksandminerals.com/aluminum/process.htm.

More sites on the history of aluminum

A page on aluminum appears in the "It's Elemental" feature of *C&E News* at http://pubs.acs.org/isubscribe/journals/cen/81/i36/html/aluminum.html. Coverage here is from an historical perspective and that of a chemistry professor—probably more appropriate for teachers than students, since it gives a personal statement.

Alcoa (previously the Aluminum Company of America) Web site has a section discussing "Alcoa's 125 Years", providing a history of the company's (and aluminum's) development since Charles Martin Hall. View it at http://www.alcoa.com/global/en/about_alcoa/time_machine/time_machine_html.asp.

You can read Charles Martin Hall's own description of the research he did on the road to discovering the Hall-Héroult process. This pdf is his acceptance speech for the Perkin Medal in 1911: http://www.alcoa.com/global/en/about_alcoa/pdf/HALL_1911.pdf.

You can view one of Hall's patents at Google patents: http://www.google.com/patents?id=Lk1OAAAAEBAJ&dq=400666.

More sites on the effect of impurities on melting point

A McMaster University web page describes why and how an impurity affects the melting temperature of a solid: http://www.chemistry.mcmaster.ca/~chem2o6/labmanual/expt1/exp1b-i.html.

This PowerPoint presentation discusses melting points and their use to identify substances: http://faculty.swosu.edu/william.kelly/mp_pl.ppt.

More sites on aluminum production

Alcoa has joined forces with the Jamaican government in Jamalco, a joint company that mines and processes bauxite into alumina which it then exports. This site provides a glimpse of the company: http://www.alcoa.com/jamaica/en/home.asp.

Alcoa plans to partner with Iceland's government to construct an aluminum production plant in Iceland, utilizing its geothermal energy and hydroelectric power from a dam. This is all part of "Iceland's Move to Renewable Energy" (*C&E News*, October 16, 2006): http://pubs.acs.org/isubscribe/journals/cen/84/i42/html/8442gov1box.html.

"It All Starts with Dirt" is an Alcoa Web site that describes the complete process for producing aluminum. It is geared to students. (http://www.alcoa.com/global/en/about_alcoa/dirt.asp)

This very extensive site offers software for the industrial-scale aluminum producer to optimize input and output of the smelter. But it also offers a page dedicated to the Hall- Héroult Process, complete with photos and diagrams of the internal workings of the electrolytic cell. (http://www.peter-entner.com/E/Theory/PrincHH/PrincHH.aspx)

The Metallurgy for Dummies Web site has a page on aluminum production at http://metallurgyfordummies.com/the-bayer-and-hall-heroult-process/. The page contains diagrams of the Bayer process and the Hall-Héroult process, and the text accompanying the diagrams describes the process. There are also several YouTube videos embedded in the Web page that show (in very low-resolution) the aluminum electrolytic cell and what appears to be a student Rube Goldberg type of apparatus that simulates aluminum production.

This YouTube video shows the entire process of aluminum production, from bauxite to final aluminum ingots: http://www.youtube.com/watch?v=fa6KEwWY9HU&feature=player_embedded.

This YouTube video from How it's Made describes how aluminum foil is made: http://www.youtube.com/watch?v=f4OTj9yNOak&feature=player_embedded. Note that the first 1:07 discusses cocoon silk from butterflies. (You can skip this.)

More sites on sustainability

Alcoa's approach to sustainability in products, resources and operations can be found at http://www.alcoa.com/sustainability/en/info_page/home.asp.

More sites on bauxite

A pamphlet briefly describing the history of the production of bauxite in Bauxite, Arkansas is found at http://www.geology.arkansas.gov/pdf/pamphlets/Bauxite.pdf. The file includes production data at Bauxite from 1888-1981.

Professor James St. John at the Newark campus of Ohio State University provides several close-up photos of Arkansas pisolitic bauxite ("composed of concentrically layered rounded structures called oolites, if relatively small, or pisolites, if relatively large"). The photos, as well as a brief description of bauxite, can be found here: http://www.newark.osu.edu/facultystaff/personal/jstjohn/Documents/Common-rocks/Bauxite.htm.

This very brief video clip (0:27) shows bauxite being strip-mined and dumped into a truck: http://www.youtube.com/watch?v=NCAA4nY1bek&feature=player_embedded

More sites on recycling

Check out "Carl the Can Man", a 3-minute entertaining (?) video at Alcoa: http://www.alcoa.com/global/en/news/alcoa_video.asp?videoid=129.

The Can Manufacturers Institute has a web page chock-full of trivia statements (it calls them, "fun facts") about recycling of aluminum cans. View it at http://www.cancentral.com/funFacts.cfm.

More sites on the Washington Monument and its aluminum cap

This article, "The Point of a Monument: A History of the Aluminum Cap of the Washington Monument", from JOM—the Minerals, Metals and Materials Society journal—provides an extensive discussion of the small aluminum cap that sits atop the Washington Monument (http://www.tms.org/pubs/journals/JOM/9511/Binczewski-9511.html).

For a very comprehensive report on the history and structure of the Washington Monument from the National Parks Service, see http://www.nps.gov/history/history/online_books/wamo/wash_hsr1.pdf. This 486-page report was published in 2004, so it does not include the recent investigative/repair work done as a result of the recent 2011 earthquake.

This 17-page Web page provides food for thought re: the mathematical/ geometrical relationships among the component parts of the Washington Monument and its design (http://www.scribd.com/bernardpietsch/d/6378299-The-Washington-Monument-Icon-by-Design).

More sites on red mud flood in Hungary

This site from the Atlantic shows photos of the flooded area in Hungary a year after the deluge: http://www.theatlantic.com/infocus/2011/09/a-flood-of-red-sludge-one-year-later/100158/.

The October 25, 2010 issue of *C&E NEWS* contains an article, "Recycling Red Mud," that describes the status of red mud in aluminum production worldwide: http://cen.acs.org/articles/88/i43/Recycling-Red-Mud.html. (available to ACS members only)

More sites on the aluminum can

A copy of the September 1994 *Scientific American* article by Hosford and Duncan entitled "The Aluminum Beverage Can" can be found here at the chymist.com site:

http://www.chymist.com/Aluminum%20can.pdf. The 7-page article details the construction process of manufacturing the beverage can and contains a full-page illustration of a cut-away view of a can to show its construction.

For information on aluminum cans, including how they're made and how they're recycled, see Earth911.com's Web page here: http://earth911.com/recycling/metal/aluminum-can/facts-about-aluminum-recycling/.

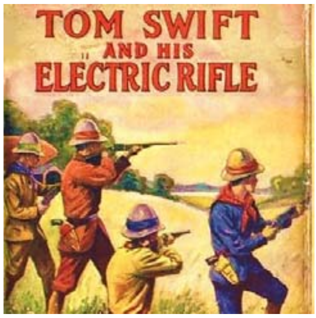
Tasers

Background Information (teacher information)

More on Tom Swift and his electric rifle

In the 1911 book “Tom Swift and His Electric Rifle” the ghostwriters at the Stratemeyer Syndicate, working under the pseudonym of Victor Appleton, described the electric rifle in the following excerpt:

> “How does it work’” asked Ned, as he looked at the curious gun. The electric weapon was not unlike an ordinary heavy rifle in appearance save that the barrel was a little longer, and the stock larger in every way. There were also a number of wheels, levers, gears and gages on the stock.
>
> “It works by electricity,” explained Tom. “That is, the force comes from a powerful current of stored electricity.”
>
> “Oh, then you have storage batteries in the stock?”
>
> “Not exactly. There are no batteries, but the current is a sort of wireless kind. It is stored in a cylinder, just as compressed air or gases are stored, and can be released as I need it.”
>
> “And when it’s all gone, what do you do?”
>
> “Make more power by means of a small dynamo.”
>
> “And does it shoot lead bullets?”
>
> “Not at all. There are no bullets used.”
>
> “Then how does it kill?”
>
> “By means of a concentrated charge of electricity which is shot from the barrel with great force. You can’t see it, yet it is there. It’s just as if you concentrated a charge of electricity of five thousand volts into a small globule the size of a bullet. That flies through space, strikes the object aimed at and—well, we’ll see what it does in a minute. Mr. Jackson, just put that steel plate up in front of the scarecrow; will you?”
>
> The engineer proceeded to put into place a section of steel armor-plate before the stuffed figure.
>
> “You don’t mean to say you’re going to shoot through that, do you?” asked Ned in surprise.
>
> “Surely. The electric bullets will pierce anything. They’ll go through a brick wall as easily as the x-rays do. That’s one valuable feature of my rifle. You don’t have to see the object you aim at. In fact you can fire through a house, and kill something on the other side.”
>
> “I should think that would be dangerous.”
>
> “It would be, only I can calculate exactly, by means of an automatic arrangement, just how far the charge of electricity will go. It stops short just at the limit of the range, and is not effective beyond that. Otherwise, if I did not limit it and if I fired at the scarecrow, through the piece of steel, and the bullet hit the figure, it would go on, passing through whatever else was in the way, until its power was lost. I use the term ‘bullet,’ though as I said, it isn’t properly one.”
>
> “By Jove, Tom, it certainly is a dangerous weapon!”



> “Yes, the range-limit idea is a new one. That’s what I’ve been working on lately. There are other features of the gun which I’ll explain later, particularly the power it has to shoot out luminous bars of light. But now we’ll see what it will do to the image.”
>
> Tom took his place at the end of the range, and began to adjust some valves and levers. In spite of the fact that the gun was larger than an ordinary rifle, it was not as heavy as the United States Army weapon.
>
> Tom aimed at the armor-plate, and, by means of an arrangement on the rifle, he could tell exactly when he was pointing at the scarecrow, even though he could not see it.
>
> “Here she goes!” he suddenly exclaimed.
>
> Ned watched his chum. The young inventor pressed a small button at the side of the rifle barrel, about where the trigger should have been. There was no sound, no smoke, no flame and not the slightest jar.
>
> Yet as Ned watched he saw the steel plate move slightly. The next instant the scarecrow figure seemed to fly all to pieces. There was a shower of straw, rags and old clothes, which fell in a shapeless heap at the end of the range.
> (http://www.gutenberg.org/files/3777/3777-h/3777-h.htm#Ch_1)

Compare that bit of science fiction with this description recorded in the 1974 patent for the Taser by John Cover:

> A weapon for subduing and restraining includes a harmless projectile that is connected by means of a relatively fine, conductive wire to a launcher which contains a power supply. The projectile is intended to contact a living target without serious trauma and to deliver an electric charge thereto sufficient to immobilize. In different embodiments the projectile can be a pellet, a net or a combination of pellets and a net. The magnitude and frequency of the electrical impulses can be controlled at the launcher, and would range, in effect, from immobilizing to potentially “lethal” levels.
> (http://www.google.com/patents?id=j499AAAAEBAJ&printsec=abstract&zoom=4#v=onepage&q&f=false)

John H. “Jack” Cover was the inventor of the Taser. He reportedly was inspired by an article about a man who inadvertently walked into an electrified fence and survived, although he was temporarily immobilized. Cover was the Chief Scientist for the company that headed up (NASA’s) Apollo Moon Landing program. In the 1960s he read about President Lyndon Johnson’s Crime Commission report that urged the development of nonlethal weapons development to combat airplane hijacking and civil unrest that characterized the 60s. It is interesting to note that he began to develop the Taser in 1966 and only completed his work in 1974 when he applied for the patent noted above. As the article notes, Cover created the term “Taser” in recognition of Tom Swift, the boy hero of the series of books published in the early 1900s. The original Taser used gunpowder as the propellant and was, therefore, classified as a firearm according to U.S. Bureau of Alcohol, Tobacco and Firearms (ATF). In 1994, Cover approached the company that is now the leading manufacturer of Tasers, Taser International, to help him develop the compressed nitrogen propellant which is now used in the device. This development removed the “firearm” label from the Taser. Today more than 15,000 law enforcement agencies use Tasers, and the device has been used more than 1.32 million times in the field.

More on Tasers

As the article says, a Taser fires two metal pointed dart-like electrodes that are designed to penetrate clothing and skin. The electrodes are attached to insulated metal wires, some as long as 35 feet (10.6m). A cartridge filled with compressed gas like nitrogen, air or carbon dioxide propels the electrodes, each with a mass of about 1.6 g, from the weapon to the target at a velocity of about 55 m/s, about one fifth the velocity of a bullet. This cartridge must be replaced after each firing. The electrodes deliver a high-voltage, low current shock to the person being Tasered. The power source for this charge are typically 8–12 volt batteries connected to a capacitor (called a "shaped pulse" capacitor) which is charged by the batteries and stores high-voltage energy. This capacitor is what increases the voltage of the electricity from the 8–12V battery to the 50,000V often cited as the delivered laser output.

Here are a few published electrical characteristics of the Taser M26, the best-known Taser model:

Voltage at Output: 50,000 Volts (50 kV)
Peak Current: 18 Amps
Current at Output: 162.48 mA average
Current at Output Range 100 to 500 mA
Repetition Rate: 2 to 40 pulses per second
Pulse width duration: 10 μs to 100 μs
Output Pulse Energy: 1 to 3 J
Body Impedance Reference: 1000 Ohms

The 50,000 volts referenced above is misleading. It is accurate, but does not tell the story about the effect of the Taser on humans. First of all, the high voltage is required in order for the Taser to work since the current typically has to pass through clothing and air, neither of which are good conductors. Second, Taser International says that its M26 unit actually *delivers* about 1200 volts with a current of between 0.002 and 0.02 amps (0.02 amps on average). What can we compare that to? In the U.S. house current is 120 volts. A 60-watt light bulb, for example, draws 0.5 amps, while a toaster draws about 5 amps. And this is important because it is the current (amperes) that damages tissue. (See "More on electro-muscular disruption," below)

A short summary of relevant electricity theory is in order. Recall that electricity is a flow of electrons in a conductor, like a copper wire or an electrolyte. Voltage and current are two separate ways of measuring electricity. Voltage is the force that pushes the electrons through the circuit, and current—measured in amperes or amps—is the rate of flow of electrons through the conductor. A circuit can have high voltage and low current or the reverse. An analogy to the former case might be a dentist's water jet—high voltage, low current (high-speed, thin-stream jet of water, but not much of it. A storm sewer, on the other hand represents low voltage, high current since a lot of water passes through the pipe but at low pressure.

The Taser International web site (http://www.taser.com/research-and-safety/how-a-taser-works) explains the electricity involved in a somewhat different way:

> Electricity is a flow of energy, or more specifically a flow of electric charge within a conductor. That conductor can be a copper wire, or it can be the human body. Much like water flows through a pipe, electrons flow through a wire. When we measure electricity, there are two key measures – Voltage, measured in Volts, and Current, measured in Amperes.

> Voltage, which is also called Electro-Motive Force, is similar to the pressure in a water hose. The voltage provides the “pressure” to push an electric current through the wire.
>
> Current is the measure of the actual flow of electricity – how many electrons are actually flowing through the wire.
>
> In our analogy to flowing water, voltage is like pressure, measured in pounds per square inch. Current is the flow rate, similar to gallons per second in our water analogy.
>
> By way of analogy, let’s compare a waterfall to rainfall. The pressure or voltage behind each droplet of water in the waterfall is actually a lot less than for each rain drop – because the rain drop is falling from a much greater height. So, the “voltage” of this waterfall is much less than for rain. However, the rate of flow or "current" for the waterfall is much, much higher than for the rain, which falls in small droplets separated in space and time compared to the continuous flow of the waterfall. Standing under the waterfall would certainly be a very dangerous place to be – much more so than in the rain. Similarly, being exposed to a high current electrical current – like the one out of your wall outlet, can be very dangerous, even at moderate voltages like 110 volts. Exposure to high voltage, low current shocks – such as a static discharge on a dry day, is far less dangerous. Static shocks regularly exceed 30,000 volts, yet they deliver very low amounts of electric charge, and there has never been a reported injury directly from the effects of a static shock, although there have been some secondary injuries from people who were surprised and may have fallen, etc.

Tasers work by passing the electric current through a circuit made up of the source (in the Taser unit), the wires that are propelled to the target and anchored there by the barbed electrodes and the tissue of the person being subdued. What effect does that electric current have on that tissue?

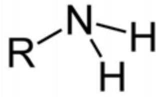
More on electro-muscular disruption

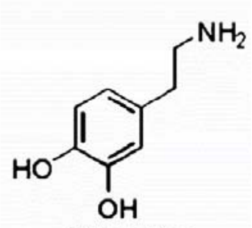
The article describes the effect of the Taser’s electric current on the muscles of a victim. In broadest terms the electric current from the Taser interferes with the natural functioning of nerve cells causing muscle cells to contract involuntarily, thus immobilizing the victim. As the article states, muscles contract in response to “instructions” from nerve cells, or neurons. The normal process uses a combination of electrical and chemical signals that originate in the brain and are transmitted through the nervous system to muscle cells.

The article focuses on the transmission of signals via neurons, which act as transducers. That is, they have the ability to convert one type of energy to another. When the brain transmits to neurons an electrical signal to contract a muscle, the neurons can convert that small amount of electric current into chemical substances called neurotransmitters that allow the signal to be transmitted across the synaptic cleft between neurons, a space of between 20 and 50 nanometers. The mechanism for this conversion is also described in the article. The pre-synaptic neuron receives a small electric signal which causes it to change the permeability of its cell wall, allowing sodium ions dissolved in the extracellular fluid to enter the cell. This increase in sodium ion concentration within the cell triggers the release of neurotransmitters into the synaptic gap between the pre-synaptic and post-synaptic cell. When the post-synaptic cell receives the neurotransmitter molecule, an electric current is generated and the process continues to the next neuron. Eventually the signal that originated in the brain reaches a muscle cell and the muscle contracts when the neurotransmitter acetylcholine binds with a muscle-regulating protein called troponin. When the signal is no longer received the neurotransmitter molecules return to vesicles in the cell called sarcoplasmic reticulum.

Ions play an important role in transmitting electric signals *within* a given neuron (as opposed to transmitting signals *between* neurons. When a neuron is stimulated, an electric impulse called an action potential moves through the neuron at an approximate velocity of 5 m/s. This action potential, or voltage, is created within a neuron by the flow of positively-charged sodium ions across the cell wall, as described above and in the article. This flow of positive ions creates a small electric potential (voltage) of between 40 mV and 80 mV within the neuron that causes the current to flow. As this current reaches the end of the neuron, ions again flow across the cell wall and signal the release of neurotransmitters into the synaptic cleft. You can view a simulation of action potentials and neurotransmitters here: http://science.education.nih.gov/supplements/nih2/addiction/activities/lesson2_neurotransmission.htm.

Chemically, neurotransmitters are relatively small molecules that have amine functional groups, which look like the representation at right. "R" is any organic molecule. So, for example, the neurotransmitter dopamine (below) has this overall structure:





Dopamine

In general neurotransmitters may be amino acids, amino acid derivatives or peptides. Glycine, an amino acid, is a neurotransmitter. Dopamine, mentioned above, is derived from the amino acid tyrosine. Below is a list of a few common neurotransmitters and their roles in the body. It is thought that there may be as many as fifty neurotransmitters in humans.

Neurotransmitter	**Role**
Acetylcholine	Used by spinal cord motor neurons to cause muscle contraction and by many neurons in the brain to regulate memory.
Dopamine	Produces feelings of pleasure when released by the brain reward system. Dopamine has multiple functions depending on where in the brain it acts.
Gamma-aminobutyric acid	Is important in acid producing sleep, reducing anxiety, and forming memories.
Glutamate	Is important in learning and memory.
Glycine	Used mainly by neurons in the spinal cord.
Norepinephrine	Acts as a neurotransmitter and a hormone. In the peripheral nervous system, it is part of the fight-or-flight response. In the brain, it acts as a neurotransmitter regulating blood pressure and calmness.

Serotonin	Involved in many functions including mood, appetite, and sensory perception.

The electric pulse delivered by the Taser overwhelms the natural neuromuscular process by increasing the rate at which nerve signals are transmitted through neurons, resulting in loss of muscle control. The force with which skeletal muscles expand or contract depends on the *rate* at which cells are stimulated. At a rate of 70 pulses per second, for example, muscles contract violently and with permanent damage. This condition is called tetanus and is similar to the tetanus we know is the result of a neurotoxin substance in the body. Note, from the Taser data above, the Taser pulse rate is between two and forty pulses per second, with the standard rate being 19 pulses per second. At these rates, no permanent skeletal muscle damage will be caused. (see “More on Taser safety, below.)

The relationship between electricity and muscle movement can be traced to the experiments of Luigi Galvani in the late 1700s. During his experimentation with static electricity, Galvani discovered that a static charge could cause the muscles of a dead frog to react. This discovery connected the idea of ions, electrolytes and chemical reactions with the behavior of nerves and muscles in living things, a field called electrophysiology today. However, Galvani believed that the energy originated in the muscles and not chemically. Alessandro Volta, a contemporary of Galvani, advanced the connection between biological activity and direct current produced by chemical reactions. This line of inquiry led Volta to build the first battery, the voltaic pile.

More on Taser safety

One of the underlying questions in the article is whether Tasers are safe to use on humans. There seems to be no single answer to this question, nor is it clear how to phrase the question. We might ask, “Are Tasers harmful?” or we might ask “Are Tasers harmful to otherwise healthy individuals?” The first question will produce generally positive answers, but the second version of the question emphasizes the potential risk that Tasers pose to addicts, those with mental disorders and those with pre-existing heart conditions.

You could use this article to illustrate to students the importance of asking questions so that science can provide an answer. You can also use this article to illustrate the importance of evidence in science and how there might be conflicting evidence related to a given question.

For example, a 2011 report issued by the National Institute of Justice, the research and development arm of the U.S. Department of Justice, says that “While exposure to [Tasers] conducted energy devices (CEDs) is not risk free, there is no conclusive medical evidence that indicates a high risk of serious injury or death from the direct effects of CEDs. Field experience with CED use indicates that exposure is safe in the vast majority of cases. Therefore, law enforcement agencies need not refrain from deploying CEDs, provided the devices are used in accordance with accepted national guidelines.” On the other hand, the same report indicates that “a number of individuals have died after exposure to a CED during law enforcement encounters. Some were normal, healthy adults; many were chemically intoxicated or had heart disease or mental illness. These deaths have given rise to questions from both law enforcement personnel and the public regarding the safety of CEDs.” (https://www.ncjrs.gov/pdffiles1/nij/233432.pdf)

Documented reports indicate that there have been 515 Taser-related deaths in the U.S. between 2001 and 2011. Is that too many? How does society decide? And who decides? There are more questions than answers in the debate about Taser safety. Further complicating the issue is the role of personal and social values. Do we value more the fact that using Tasers seems to save lives as law enforcement officials go about their work, or does the loss of 515 Taser-related lives outweigh the prospect of lives being saved by Taser use? It is a complicated debate, and you might well engage your students to do their own research about this issue. (See Out of Class Activities and Projects for ideas.)

Do ideas from science have anything to say here? What levels of electricity are safe and what effects does electricity have on the body? As was mentioned earlier, the two main ways of measuring electricity are voltage and amperage. Volts are a measure of the potential difference or electrical force in a circuit. Amperes measure the amount of current (number of electrons) flowing in the circuit. What makes up the complete circuit when a Taser strikes a person?

Most students will know, of course, that a complete circuit is required for current to flow. When a Taser is fired, the person struck by the electrodes completes the circuit between the two electrodes. Students may need to be reminded that about 60% of the human body is water. Of that water, about two thirds is contained within cells in the body and the other one third is extracellular. Important here is the fact that the water is not pure water but a solution made up of many solutes, some of which are ionic compounds, making the solution an electrolyte. This is what allows a current to flow through the body. Human tissue offers resistance to the current flow. So the three factors in Ohm's Law—volts, amperes and ohms—are all accounted for when a Taser strike a person.

As stated above, it is the current (amperes) that determines the damage done in the body. As in all cases, electric current is partially converted to heat, and this heat causes localized tissue damage. This is minor in most cases. The intent of the Taser current is to interfere with the body's neuromuscular system. What levels of current are dangerous? The table below gives some approximations, based on tests done by electrical engineers in their field work.

Amperes (direct current) (milliamps)	**Effect**
1.0 mA	Slight sensation felt in hands
5.2 mA	Lower threshold of pain perception
62 mA	Painful, but muscle control maintained
76 mA	Muscles contract involuntarily
90 mA	Severe pain, difficulty breathing
500 mA	Possible heart fibrillation after 3 seconds

One other Taser factor is important here, that does not show up in the above table. In a Taser, the pulse rate (or frequency) of the charge makes a difference. The Taser sends out the current at a rate 19 pulses per second (for three seconds), This frequency serves to augment the effect of its 20 mA average charge to an equivalent of about 60–70 mA so that muscle control is lost temporarily.

So it would seem that the energy delivered by the Taser is well within normal safety limits. However, there are so many other variables in the real world that might affect the relationship between a Taser charge and its effect on its human target as the 515 Taser-related deaths would suggest. Even Taser International, the main producer of Tasers in the U.S., has a long list of warnings on its web site. Among them are:

1. The TASER device can cause strong muscle contractions that may cause physical exertion or athletic-type injuries to some people. These muscle contractions can result in strain-type injuries such as hernias, ruptures, or other injuries to soft tissue, organs, muscles, tendons, ligaments, nerves, joints, and stress/compression fractures to bones, including vertebrae. People with pre-existing injuries or conditions such as osteoporosis, osteopenia, spinal injuries, diverticulitis, or previous muscle, disc, ligament, or tendon damage may be more susceptible to these types of injuries.
2. These strong muscle contractions usually render a subject temporarily unable to control his or her movements and may result in secondary injuries. Under certain circumstances, this loss of control can elevate the risk(s) of serious injury or death. These circumstances may include, but are not limited to, use of the TASER device on a person who is physically infirm or pregnant, or a person on an elevated or unstable platform, operating a vehicle or machinery, running or in water where the inability to move may result in drowning.
3. When practicable, avoid prolonged or continuous exposure(s) to the TASER device electrical discharge. The stress and exertion of extensive repeated, prolonged, or continuous application(s) of the TASER device may contribute to cumulative exhaustion, stress, and associated medical risk(s). Severe exhaustion and/or over-exertion from physical struggle, drug intoxication, use of restraint devices, etc. may result in serious injury or death. The TASER device causes strong muscle contractions, usually rendering a subject temporarily unable to control his or her movements. Under certain circumstances, these contractions may impair a subject’s ability to breathe. If a person’s system is already compromised by overexertion, drug intoxication, stress, pre-existing medical or psychological condition(s), etc., any physical exertion, including the use of a TASER device, may have an additive effect in contributing to cumulative exhaustion, stress, cardiovascular conditions, and associated medical risk(s).
4. TASER probes can cause significant injury if deployed into sensitive areas of the body such as the eyes, throat, or genitals. If a TASER probe becomes embedded in an eye, it could result in permanent loss of vision. Repetitive electrical stimuli can induce seizures in some individuals.
5. In most areas of the body, wounds caused by TASER probes will be minor. TASER probes have small barbs.
6. Use of a TASER device in drive (or touch) stun mode can cause marks, friction abrasions, and/or scarring that may be permanent depending on individual susceptibilities or circumstances surrounding TASER device use and exposure.

So the question of Taser safety remains unresolved. Many law enforcement agencies believe that Tasers are safe. Many human and civil rights advocates and some health agencies disagree. This would be a good topic for student research and debate. (See Out of Class Activities and Projects for ideas.)

More on electrolytes

Perhaps by this time in your course, students will already have learned about electrolytes. If not, a quick review: Electrolytes are aqueous solutions in which the solute is present, either totally or in part, in the form of ions. That means that the solute has dissociated or ionized when it dissolved. If the solute is present entirely as ions, the solution is considered a strong electrolyte. If the solute only partially ionized or dissociated, the solution is called a weak electrolyte. Pure water is a non-electrolyte. One of the most important characteristics of electrolytes is their ability to conduct an electric current. The ions in solution carry charge through the solution.

A majority of the human body is water, but not pure water. Minerals like sodium chloride and other sodium or potassium salts in the diet become solutes that produce ions when dissolved. So we can say that most of the human body is an electrolyte. This is very important when it comes to neurons and other cells transmitting electric current that carry nerve impulses. Neurons maintain different concentrations of potassium and sodium ions inside the cell versus outside the cell. Cell walls are impermeable to these ions, but cells have the ability to transport ions selectively across the cell walls or to change the cell wall permeability to these cations. Anions cannot pass through the cell walls. By one or both of these mechanisms, cells are able to move ions in or out of the cell and thus create an electrical potential difference within the cell. In this way the cell creates a small voltage that transmits electric charge along the neuron. (See More on electro-muscular disruption for more details.) The normal function of the nervous system, then, depends on ions present in the electrolyte.

As mentioned earlier, the most important ions for proper functioning of the nervous and muscle systems are sodium ions (Na^+), potassium ions (K^+) and chloride ions (Cl^-). Sodium and chloride ions are found in higher concentrations outside cells, while potassium ions are in higher concentrations inside cells. It is primarily the migration of sodium ions across neuron cell walls that creates the action potential, or voltage, that drives nerve impulses through individual neurons.

Sodium ions play an important role in maintaining the balance of body fluids. They stimulate the absorption of water and sucrose during exercise as well as triggering the thirst mechanism. An extremely low sodium level is called hyponatremia and is characterized by nausea and vomiting, muscle fatigue, confusion and, in acute cases, seizures. Potassium ions help to control muscle contractions, including heartbeat. Chloride ions help maintain body fluid balance and acid-base balance in the body. Other ions important for normal body functioning are calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^{1-}), phosphate (PO_4^{3-}) and sulfate (SO_4^{2-}).

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Electrochemistry—**Tasers are effective in immobilizing a person because the electric pulse they deliver interferes with the normal bioelectric functioning of nerves and muscles. Impulses are transmitted through the body by a series of electrochemical reactions, and Tasers deliver impulses that override these reactions.
2. **Biochemistry—**This article can be used to show students how most normal body processes are, in fact, the result of inter-connected chemical reactions. The sections of the article that explain how Tasers incapacitate muscles can be used as the basis for this concept.
3. **Electrolytes—**The fact that both intracellular and extracellular fluid is electrolytic in nature allows impulses to be transmitted through and between neurons in the neuromuscular system.

4. **Ions—**The existence of ions in and around cells and the semi-permeability of cells to these ions is the triggering mechanism for action potentials or voltage that sends pulses along neurons.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"A battery is needed to create an electric current."** *Batteries are one way to produce an electric current. However, in the case of the small currents needed in humans to make their nervous system function, neurons (nerve cells) have the ability to create a small potential difference (voltage) by moving cations in or out of the cell, leaving a grater positive charge outside the cell and a greater negative charge inside the cell. This difference in concentration is short-lived but sufficient to create the voltage needed to power the current in the cells.*

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

1. **"How can a Taser deliver 1200 volts without killing a person?"** *The article says that volts measure the potential difference between the two Taser electrodes. That is actually the electric force that pushes electrons through the person. But the article also says that it is the number of electrons flowing through the person that is harmful. This property of electricity is measured in amperes, and Tasers deliver between 0.002 and 0.02 amperes. That's because the human body offers resistance to the flow of electrons, and body resistance varies widely, depending on multiple factors such as percent body fat, distance between electrodes, and absence or presence of water either inside or outside the body (in the form of perspiration, for example). Body resistance can be in the tens of thousands of ohms, for example. Ohm's Law relates the three variables discussed here—voltage, current and resistance: Current = Voltage/Resistance.*
2. **"How can a person be conscious and not be able to move?"** *The article says that people who are struck by a Taser remain conscious but are unable to move. That's because the frequency and amperage of a Taser is such that it affects primarily the nerves that control skeletal muscles. The rest of the central nervous system remains unaffected.*
3. **"How does it feel to get Tasered?"** *Watch a video of a reporter and police officer subjecting themselves to a Taser and reflecting on how it feels at http://www.youtube.com/watch?v=_sN4bvQrBBY.*
4. **"Why doesn't a Taser cause the heart to stop? It's a muscle, isn't it?"** *There are two basic reasons. First, the cardiac muscles are arranged in a different configuration than skeletal muscles. Skeletal muscles tend to be made up of long cells that stretch for tendon to tendon. Cardiac muscle cells are much more interconnected and offer low resistance. So cardiac muscle tissue is more sensitive to electric shock than skeletal muscle. What protects the heart from a Taser? The skeletal muscles are arranged in bands around the rib cage which protects the heart. If the Taser probes deliver an electric pulse to these muscles, they carry the current along their length rather than deliver it to the heart, which lies deeper inside the body. A second difference is that cardiac muscle responds to a different combination of current and frequency than skeletal muscle. Tasers are engineered to affect skeletal muscle.*

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

1. You can choose from a series of neuroscience PowerPoints on this site from Harvard University: http://outreach.mcb.harvard.edu/lessonplans_S05.htm. Lesson topics include basic nervous system mechanisms and neuron structure and function.
2. This activity relates the concentration of ions to muscle contraction in the heart: http://www.teachengineering.org/view_lesson.php?url=collection/uva_/lessons/uva_pump_bme0607_less/uva_pump_bme0607_less.xml.
3. This video from the National Institutes of Health explains how neurons function: http://science.education.nih.gov/supplements/nih2/addiction/guide/lesson2-1.htm. The "Student Activities" tab provides several videos that describe the process. http://science.education.nih.gov/supplements/nih2/addiction/guide/guide_lessons_toc.htm
4. You can show this video http://blogs.howstuffworks.com/2009/12/21/how-twitching-frog-legs-work-a-little-gross-yes-but-fascinating/ which demonstrates the effect that salt has on the action potential of frog leg muscles. The notes that accompany the video explain that adding salt to fresh frog legs creates sodium ions around the muscles cells which, in turn, produces the action potential needed to cause the legs to twitch. (See More on electro-muscular disruption for details.)
5. If you have the materials to show conductivity of solutions as a demonstration, you can do so to reinforce the concept that cell behavior is dependent on the presence of electrolytes. See http://chemdemos.uoregon.edu/pages/detail.php?&page=1&id=b8c2b9ed148125c275d222a139d196db# for a suggested procedure. NOTE: It would be **much** better; i.e., safer, to use a battery-powered conductivity tester, instead of the plug-in type described in this demonstration.

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

1. You might assign teams of students to select one or more of the studies cited on Taser International's web site and research them for fairness or bias. (http://www.taser.com/research-and-safety/science-and-medical)
2. You can assign students to research the safety of Taser use, and summarize their findings in a letter to your local police department. (See More on Taser safety, above, and Sites on Taser safety, below)

References (non-Web-based information sources)

Kimbrough, D. Can Chemistry Stop What's Bugging You? *ChemMatters* **2004** *22* (2), pp 8-10. This article has a very brief section on neurotransmitters on page 9.

Web Sites for Additional Information (Web-based information sources)

More sites on Tasers

This online text, titled *Taser Conducted Electrical Weapons: Physiology, Pathology and the Law*, from Springer, has 32 chapters that extensively cover all aspects of Tasers http://www.scribd.com/doc/32426047/TASER-Conducted-Electrical-Weapons.

Taser International has an extensive web site with hundreds of resources about Tasers. If you use this site, you should remember that you will not find any significant negative information about Tasers here: http://www.taser.com/.

This "How Stuff Works" site provides some basics about the working of the Taser: http://electronics.howstuffworks.com/gadgets/other-gadgets/stun-gun5.htm.

This site from IEEE, an electrical engineering professional society, gives excellent basic electrical information about Tasers: http://spectrum.ieee.org/consumer-electronics/gadgets/how-a-taser-works.

More sites on Taser safety

Taser International's extensive web site also includes material on their safe use. (http://www.taser.com/)

An article from the National Commission on Correctional Health Care examines some of the possible injuries from Tasers. (http://www.ncchc.org/pubs/CC/tasers.html)

This article from Scientific American gives an overview of Taser safety issues: http://www.scientificamerican.com/article.cfm?id=taser-electric-shock-zap-law-canada.

A 2011 report from the U.S. Department of Justice examines deaths following the use of a Taser. View it at https://www.ncjrs.gov/pdffiles1/nij/233432.pdf.

This report from the American Civil Liberties Union questions the safety of Tasers: http://www.policyarchive.org/handle/10207/bitstreams/96063.pdf.

More sites on neurotransmitters

For a simulation on neurotransmitters from the National Institutes of Health (NIH) see http://science.education.nih.gov/supplements/nih2/addiction/activities/lesson2_neurotransmission.htm.

This site explains in more detail the role of ions in neurotransmission: http://ezinearticles.com/?Our-Body-Uses-Chemicals-and-Electrical-Impulses-For-Communication&id=3475542.

This online book from Oxford University Press explains the relationship between biology, electricity and magnetism: http://www.bem.fi/book/index.htm.