

Green Chemistry

STOPPING POLLUTION BEFORE IT STARTS

You've invited your friends over for videos and a half gallon of ice cream. Just for laughs, somebody reads the label and says, "Get this! Here's what we're eating!" They rattle off something that sounds like "dihixi-hexegazorniplatz hydroxy-megadogdoo". You make a mental note to buy something natural and *chemical-free* next time. Just to be safe.

Ha! Let's try an experiment. Put the magazine down and make a list of three things that



MIKE CIESIELSKI

are free of chemicals. Easy? Take your time. We'll wait. So what did you come up with?

Organic herbal tea? Nope, lots of fragrant hydrocarbons there. Filtered water? Think again. It abounds in trace minerals along with plain old H₂O. Air? Need we mention oxygen, nitrogen, and carbon dioxide gases to name a few? Sure, you could be clever and name a vacuum, but that's more the absence of a thing.

The undeniable truth is this. We live in a chemical world. Any effort to rid ourselves of chemicals is futile. So, as we prepare to celebrate Earth Day 2003 this month, why are chemists and the chemical industries still looking like the bad guys?

Try this list. List all of the manufactured products on which your life and lifestyle depend—like antibiotics, processed foods, electricity at the touch of a button, silicon chips inside computers, perhaps even the latest fashion fad. The list is long, and few of us would want to revert to harsh frontier life, with most of our time tied up with chopping wood, hauling water, and scrubbing clothes on a washboard. But there is a nagging question: Are these advances coming at too high a price for the environment? Can we have our products and still sustain a healthy livable planet?

You're probably already bracing for the message. This is going to be all about smokestacks and acid rain. You've heard all you want to hear about that. Bad industries, bad polluters, bad consumers, bad vehicles—bad, bad, bad. Or maybe you think that because this is a chemistry magazine, we're going to defend all industrial practices, gloss over the obvious problems, and paint a rosy picture of a utopian world in which chemistry solves all problems while creating none.

Let's try a different approach. Common sense. Although your school chemistry lab is not a big manufacturing plant, you and your teacher make important process decisions every time you do an activity. And many of those decisions are a lot like those made by industrial chemists: What chemicals do we need? (Are they safe? Expensive? Can we use less and still get good results?) What solvent should we use? (Again, is it safe? Will water work as well?) How shall we heat the reaction vessel? (Will it go just as well at room temperature if we wait? Hot plate? Bunsen Burner? Microwave?) And what should we do with the wastes that accumulate? (Down the drain? In the trash can?) You're skeptical. Surely that little bit of chemistry doesn't make any difference.



DIGITAL VISION

continued on page 10

GREEN ENERGY—

When green chemists design the chemical pathway for making a product, energy use is high on their list of concerns. They look for alternative ways to make the same product, always considering whether the product would be more “benign” if made by a method requiring less energy. With many factors to consider—starting materials, solvents, and the like—the decision is seldom clear-cut.

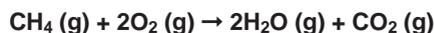
Once they’ve settled on the right chemistry, they think about finding the most efficient way to deliver the energy to the reaction. Does one

way conserve precious energy dollars and fuel resources better than other ways?

You and your teacher face similar choices when you conduct your activities in the lab. You probably decide whether to bring the reactants up to the required temperature by heating with a Bunsen burner, electric hot plate, or microwave oven. Have you asked which one is most efficient in terms of energy cost? How can you find out? We’ll get you started on the problem, and then we’ll leave it up to you to find the answer for the equipment in your lab.

The Bunsen burner

The typical laboratory burner requires natural gas—largely methane (CH_4)—that is piped in from a commercial supplier. Upon ignition, methane mixes with air in the burner to produce a flame. The complete combustion of methane in air is represented by the following equation:



This reaction is very exothermic, and the thorough mixing of the natural gas with the air by the Bunsen burner helps ensure that the reaction is relatively complete.

Of course, not all of the heat released by this reaction is actually absorbed by the materials to be heated. Some portion of the heat goes into heating up the containers or the immediate surroundings. The efficiency of the process is calculated as follows.

$$\% \text{ Efficiency} = \frac{\text{Heat absorbed by material}}{\text{Heat given off by burning natural gas}} \times 100$$

In this activity, we will measure how efficient it is to heat a sample of water using a Bunsen burner.

Be sure to wear safety goggles when operating the Bunsen burner. Conduct this activity only under teacher supervision.

1. Using the balanced equation, calculate the amount of energy (ΔH_f) for the combustion of methane. Use a handbook or textbook to look up the standard heats of formation. (Assume STP).



$$\Delta H_f = (\sum \Delta H_f \text{ products}) - (\sum \Delta H_f \text{ reactants})$$

2. Next, you need to know how *much* natural gas is delivered from the connection on your desktop over time. Suppose you had the following apparatus: **1 meter of hose, a tub or bucket for holding water, a stopwatch or clock with second hand, a 2-L soda bottle, and a variety of volumetric measuring containers such as large graduated cylinders.** How would you measure the amount of methane delivered every second? Since you’ll need to open the gas valve on your desk and the gas control valve on your Bunsen burner to the optimum settings for producing a flame of reasonable size, you’ll need to begin with some burner tests.

- Now, design a plan for collecting and measuring gas, paying particular attention to safety and how you will dispose of the natural gas you are measuring. If you are actually going to carry out the plan, **be sure you have your teacher’s approval and careful supervision before proceeding. It is very important that no open flames be present during this phase of the procedure.** After you have finished measuring, record your results for use in the completion of this activity. Or, obtain the figure from your teacher if this measurement is already available.
- After all collected methane has been safely disposed, set up a **250-mL beaker of water containing 200 mL of water on a ring stand** or support suitable for heating with the Bunsen burner. Using a **thermometer**, measure the initial temperature of the water. Then, light the burner and begin to heat the water. Start tracking the time.
- Heat the water until the temperature increases about 30–50 °C over the starting temperature. Measure the final temperature to the nearest 0.1 °C. Note the time when your heating has finished.
- Calculate the amount of heat absorbed by the water, the amount of heat released by combustion, and the percent efficiency of the heating process. Use the following equations in your calculations. (Assume STP.)

IT'S YOUR DECISION

$$\text{Heat absorbed by the water} = \text{mass of water (g)} \times \Delta T \times 4.18 \frac{\text{J}}{\text{g} \times ^\circ\text{C}}$$

$$\text{Heat released by combustion} = \frac{\text{L (gas)}}{\text{sec}} \times \frac{\text{mol (gas)}}{22.4 \text{ L (gas)}} \times \frac{\text{J}}{\text{mol (gas)}} \times \text{sec}$$

$$\% \text{ Efficiency} = \frac{\text{Heat absorbed by material}}{\text{Heat given off by combustion of natural gas}} \times 100$$

The electric hot plate

Another typical means of heating in the laboratory is the use of an electric hot plate. Design an experiment, similar to the one described on page 8, to determine the efficiency of an electric hot plate in heating.

1. The energy released by the hot plate depends on its energy rating. Look at the bottom or sides of the hot plate and look for its power rating, in watts.



2. Because a watt = 1J/sec, we can calculate the total amount of energy released from the hot plate using the equation below.

$$\text{Energy released by a hot plate} = \text{total wattage of hot plate} \times \text{time} \times \frac{1\text{J/sec}}{1 \text{ watt}}$$

The microwave oven

Although microwave ovens have been more typically used in the home, they are becoming more widely used in scientific laboratories. Use the experience and information from the previous two activities to determine the efficiency of heating a sample of water using a microwave.

1. The energy released by the microwave depends on its energy rating. Look at the bottom or sides of the microwave and look for its power rating, in watts.
2. Because a watt = 1J/sec, we can calculate the total amount of energy released from



- the microwave using the equation below.
3. Using a procedure similar to that described on page 8, heat a sample of water and use the results to calculate the efficiency of the microwave in heating the water.

$$\text{Energy released by a microwave} = \text{total wattage of microwave} \times \text{time} \times \frac{1\text{J/sec}}{1 \text{ watt}}$$

Discussion

You now have what you need to compare the efficiency of the three ways to supply heat to a reaction in your lab. But is that all you need to know? What if you wanted to think about overall costs—and we're talking about more than just dollars. For example, it does little good to choose electricity over natural gas if the power plant that generates the electricity contributes significantly more pollution than does the natural gas producer.

Here are some things to consider before making a final decision.

1. Use your household electricity and natural gas bills to calculate the cost in dollars for each of the experimental trials you did above. Calculate the cost for heating a sample of water by 10 °C for each method. If natural gas is not available in your community, use the national average price or

substitute the cost of propane. Although the cost in dollars is not a perfect reflection of the total cost to the environment, it does reflect how difficult it is to bring the energy source to market. Which energy source was most expensive? Which was least expensive?

2. There are many ways to generate electricity and produce natural gas. Some require less energy to produce than others. Using the Web and other sources, investigate which power source tends to require less energy and contributes less total pollution to your local environment.

Finally, using the information you have collected regarding efficiency, dollar cost, and environmental cost, make a recommendation for how best to minimize the energy used to heat substances in your school lab.

This activity is adapted from Ryan, M. A., Tinneland, M., Eds. *Introduction to Green Chemistry: Instructional Activities for Introductory Chemistry*; American Chemical Society: Washington, DC, 2002; pp 45–53.

continued from page 7

Now scale those decisions up to manufacturing plant level. History shows that as our nation's industries grew, manufacturing processes were largely about one thing—product. Why not? Manufacturers could tap vast supplies of starting materials to be chopped, pumped, or mined. Exhausting one vein or field, they found others just waiting to be developed. There were streams and wide-open spaces to sweep away the wastes, and the public eagerly awaited the finished products. Few, except for those living downwind or downstream from the plant, complained, and even fewer worried about whether we could have our products and a healthy planet, too.

Stopping pollution before it happens

Since it began on April 22, 1970, Earth Day has served as a day for checking the vital signs of our natural environment. For the last few decades, local Earth Day observances have been about community recycling and cleanups.

This April, although many organizations are planning more cleanup efforts, some imaginative chemists are working on a better plan. What if, they ask, we could manufacture products in such a way that we wouldn't need to haul away waste products? What if we could make products that didn't deplete the planet of precious resources, didn't take a lot of energy or dangerous solvents to make, and didn't leave unwanted byproducts behind? And what if the products themselves would degrade harmlessly when we were finished with them?

Scientists and manufacturers working toward these goals call their movement Green Chemistry. In short, their aim is to prevent pollution before it happens.

Economizing on atoms

Like all good ideas for making new and better products, the so-called green products must pass an important test. Economists call it “the bottom line”. Not only must these green products do their jobs as well as traditional products, they must be profitable for companies and comparably priced for the consumers. If they cannot meet these two tests they probably have little chance for success.

One important principle of green manufacturing is something called “atom economy”—a simple calculation of how many of the atoms found in the starting materials actually end up in the final product. Think about it. If the atoms aren't going into the product, then where are they going? Sometimes they're going up smokestacks or into groundwater! And, if you're the manufacturer, you are not only risking fines and costly cleanups, you're also throwing away valuable atoms that you've just paid for in your starting materials.

Green chemists work hard to build in manufacturing techniques with high atom economy whenever creating new products and processes. When a pharmaceutical manufacturer designed a new process for making ibuprofen, the pain reliever found in over-the-counter medications like Advil and Motrin, they nearly doubled the atom economy from 40 to 77%. The new process decreased waste and increased profits for the German pharmaceutical company Badische Anilin & Soda Fabrik (BASF), the company that developed the new synthesis.

Getting off to a safe start

In some manufacturing processes, not only the waste products but also the starting material can pose hazards. Risky exposures to danger-

ous chemicals are routinely controlled by supplying workers with protective equipment like gloves, respirators, and fume hoods. Green chemists argue that many of these exposure risks can be eliminated by simply choosing safer starting materials.

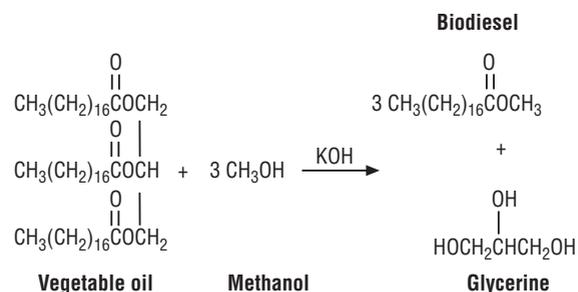
Large quantities of adipic acid ($\text{HOOC}(\text{CH}_2)_4\text{COOH}$) are needed every year for the industrial production of nylon, polyurethane, lubricants, and plasticizers. The typical starting material for making adipic acid is benzene, a known cancer-causing agent. Recently, Karen M. Draths and John W. Frost, chemists at Michigan State University, have developed a greener synthesis of this acid using a starting material that is far less hazardous than benzene, and one that is almost infinitely available in nature—glucose. Using an enzyme found in genetically altered bacteria, glucose can be converted to adipic acid without exposing workers or the environment to hazardous substances.

Using renewable resources that never run out

Green chemistry also means using renewable resources as starting materials whenever possible. Burning a fuel made from readily replaceable sources would be preferable to burning more of our ever-dwindling supply of fossil fuels. For example, many vehicles in the United States operate on diesel fuel. One promising possibility is the manufacture of *biodiesel*. As the name suggests, biodiesel is diesel fuel made from renewable resources like oils derived from farm crops such as soybeans. It is synthesized by removing glycerine—useful for making soap—from soybean or other vegetable oil. Biodiesel can even be made from recycled vegetable oils—like those left over from making fries at fast food restaurants. In the process, a potential waste product is converted to a valuable fuel. In fact, burning biodiesel smells like French fries!

The advantages are clear. Biodiesel, unlike fossil fuel-derived petroleum diesel, is a renewable source of energy. Unlike burning petroleum diesel, burning biodiesel does not emit sulfur, nor does it increase the overall amount of carbon dioxide (CO_2) in the atmosphere.

Does that mean that biodiesel doesn't release any CO_2 when it burns? No, it just means that the CO_2 released is balanced by the carbon dioxide the plants removed from the atmosphere as they grew.



Making green decisions

You may not be a green chemist, but your part is important. Green chemists hope you'll become informed and then choose those products that are, in their words, “benign by design”. 🌱

Michele La Merrill, Kathryn Parent, and Mary Kirchoff of the Green Chemistry Institute at the American Chemical Society and the editors of *ChemMatters* contributed to this article.
www.chemistry.org/education/greenchem

Teacher's guide: APRIL 2003
A supplement to *ChemMatters* magazine

[About the Articles](#)

[Lasers](#)

[Student Chemist Gets Plants to do the Dirty Work](#)

[Green Chemistry](#)

[Lightbulbs](#)

[Edible Wraps](#)

[Puzzle: Names by the Number](#)

[Answers to Names by the Number](#)

[Puzzle: ChemPUNishment from Kenwood High](#)

[Answers to ChemPUNishment](#)

[Student Questions](#)

[Answers to Student Questions](#)

[Connects to the National Science Education Content Standards](#)

[Content Reading Materials](#)

[Anticipation Guides](#)

[Graphic Organizers for Structured Note Taking](#)

© Copyright 2003, American Chemical Society. Teachers may make copies of this *Teacher's Guide* for class use. Any other reproduction is forbidden unless the ACS provides written permission. The activities described in the *ChemMatters Teacher's Guide* are intended for high school students under the direct supervision of teachers. The American Chemical Society cannot be responsible for any accidents or injuries that may result from conducting the activities without proper supervision, from not specifically following directions, or from ignoring the cautions contained in the text.

ABOUT THE ARTICLES

Question from the Classroom

How do lasers work and what is so special about laser light?

Editor's note: We're including materials and student questions for Bob Becker's April column. It hasn't been our practice in the past to include Teacher's Guide support for this popular column. But, since the Chemagination article required no additional notes, we asked Teacher's Guide Editor Frank Cardulla to write background notes for this fascinating topic instead.

Background Information

More general information about lasers

The article nicely explains the nature of laser light and how it is created. A concise answer to the question about how laser light differs from ordinary light has three points:

If biodiesel is so great, why are we still mostly burning petroleum diesel in diesel engines?

There are a number of reasons. Biodiesel does have some disadvantages. See *Background Information*.

Are there filling stations that sell biodiesel?

Yes, but they are quite rare. There are public filling stations for biodiesel in San Francisco, California and in Sparks, Nevada. There may be more by the time you read this.

Websites for Additional Information and Ideas

Green Chemistry sources are numerous. The ones below are particularly good and well supplied with links to additional information.

<http://www.epa.gov/greenchemistry/>

<http://www.chemsoc.org/networks/gcn/>

<http://www.chemistry.org/portal/Chemistry?PID=acsdisplay.html&DOC=education%5Cgreenchem%5Cindex.html>

You can also go to the American Chemical Society's Web site at <http://www.chemistry.org/> and then link by using "Green Chemistry" as your search phrase.

Any Google search will produce numerous sites related to Earth Day. A couple can be found in the *Background Information* section of this Teacher's Guide.

The Environmental Protection Agency's general Website is at:

<http://www.epa.gov/>

A site describing the operation of a diesel engine and how it differs from a normal gasoline engine can be accessed at:

<http://www.howstuffworks.com/diesel.htm>

The Chemistry of the Light Bulb—Still a Bright Idea

Background Information

Thomas Alva Edison and the invention of the light bulb

It is probably safe to say that Edison's name is so strongly linked to the electric light bulb that many, if not most, Americans credit him with the invention. Interestingly enough, historians are divided on the amount of credit he is due. It is probably reasonable to say that Edison was not the first person to invent an electric light, but he and his fellow researchers made significant improvements on the design. Because of their efforts, the light bulb became a practical and affordable commodity within reach of the average person.

The first electric light is generally credited to Humphrey Davy, an English chemist. In 1809 he connected two wires to a battery and then connected a charcoal strip between the other two

April 2003 *ChemMatters* and the National Science Education Standards

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	Green Chemistry	Student Chemist Gets Plants To Do Dirty Work	Edible Wraps	Light Bulbs	Lasers
Science as Inquiry Standard A: of abilities necessary to do scientific inquiry				✓	
Science as Inquiry Standard A: about scientific inquiry.	✓	✓	✓	✓	
Physical Science Standard B: of the structure of atoms.					✓
Physical Science Standard B: of the structure and properties of matter.	✓	✓	✓	✓	✓
Physical Science Standard B: of chemical reactions.	✓	✓	✓	✓	
Physical Science Standard B: of conservation of energy and increase in disorder.				✓	✓
Physical Science Standard B: of interactions of energy and matter.		✓		✓	✓
Life Science Standard C: of the cell.		✓			
Life Science Standard C: of molecular basis of heredity.		✓			
Life Science Standard C: of interdependence of organisms.	✓	✓	✓		
Life 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 natural resources.	✓	✓	✓	✓	
Science in Personal and Social Perspectives Standard F: of environmental quality.	✓	✓	✓		

Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.	✓	✓		✓	✓
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✓	✓	✓	✓	✓
History and Nature of Science Standard G: of science as a human endeavor.	✓	✓	✓	✓	
History and Nature of Science Standard G: of the nature of scientific knowledge.	✓	✓	✓	✓	
History and Nature of Science Standard G: of historical perspectives.	✓	✓		✓	

CONTENT READING MATERIALS

Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss their 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: 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. Cite information from the article that supports or refutes your original ideas.

Green Chemistry—Stopping Pollution Before it Starts

Me	Text	Statement
		1. All-natural, chemical-free foods are better for you than manufactured foods.
		2. Many process decisions made in a high school chemistry lab are similar to those made by chemists in a large chemical manufacturing plant.
		3. Chemists are not concerned about the environment because their livelihood depends on manufacturing more and more products.
		4. In order to increase profits, chemists must be concerned with atom conservation from reactants to products.
		5. The waste products of chemical processes are more harmful to the environment than the starting materials.
		6. Biodiesel fuel can be made from oil used to make fries at fast food restaurants.

GRAPHIC ORGANIZERS FOR STRUCTURED NOTE TAKING

These content frames 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. 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

You may want to ask students to make word maps or define the following **vocabulary words** in context.

“Student Chemist Gets Plants to do the Dirty Work”:

- phytoremediation
- chelating agent
- phytochelatin

“Edible Wraps—Safe, Strong, and Delicious”:

- polymer
- addition polymer
- condensation polymer
- polysaccharide

“Light Bulbs—Still a Bright Idea”:

- sublime
- halogen
- photon

“Question from the Classroom—Lasers”:

- photon
- laser (acronym)

Question from the Classroom—Lasers

<p>What is it?</p>	<p>What is inside?</p>
<p><i>How does it work?</i></p>	<p>How is it different from ordinary light?</p>

LASER