ChemMatters®

DEMYSTIFYING EVERYDAY CHEMISTRY

FEBRUARY/MARCH 2014

The Cool Chemistry of Ice Cream, *p. 6*

ACS Chemistry for Life™

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American Chemical Society ChemClub NEWS

365 Days of Chemistry

January 1 has already come and gone. Have you stopped writing "2013" instead of "2014" yet? Got your new calendar up? What type of calendar pictures did you choose? Are you a kitten or puppy type? Would you prefer one with your favorite cartoon character? Gorgeous sunsets and beach scenery? What about another choice—*chemistry*?

This school year, **ACS ChemClubs** received a specially designed calendar to display in the classroom. Each month's page showcases a topic and its chemistry, often with a photo of ChemClub members in action. February's page, with its connection to Valentine's Day, offers sweet treats, explaining why eating chocolate can make us feel happy, along with a photo of ChemClub members making candy. A couple of months later, you will find a page on toys with a recipe to make your own slime and learn about how it forms.

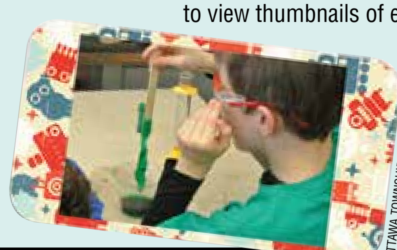
CHEMCLUB SCHOOL YEAR CALENDAR

Take a sneak peek at the July 2014 calendar page about fireworks

Each month's calendar page is matched to an online **"Activity of the Month"** at the ACS ChemClub Web site. Visit each one, and find demos, labs, videos, and more about each topic. Head to www.acs.org/chemclub to get started! Click on the current "Activity of the Month" link on the home page, or "Activities" in the menu bar to view past months' activities.

Want to see the calendar pages for yourself? Visit www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/calendar.html to view thumbnails of each calendar page. Click on each one to see a larger version. Get your monthly dose of cool chemistry!

—Erica K. Jacobsen


OTTAWA TOWNSHIP HIGH SCHOOL, OTTAWA, ILL.

A student gets slimed during an activity with ChemClub members at Ottawa Township High School, Ottawa, Ill.

Four Quarters of Fun

Besides receiving freebies such as the calendar you read about in this article, each quarter of the school year brings an envelope filled with new activities for ChemClubs to try. **During 2013–2014, ChemClubs get packets with themes of Art and chemistry, Chemistry of the Senses, Chemists Celebrate Earth Day, and National Chemistry Week.** Want to get your own? ***Start a ChemClub!*** Visit **www.acs.org/chemclub** to find out more.

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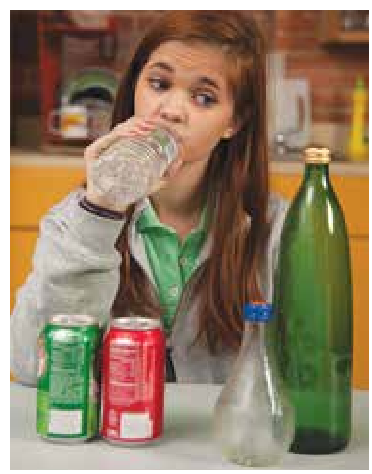

MIKE CIESIELSKI

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ON THE COVER: MIKE CIESIELSKI PHOTOGRAPHY AND ISTOCK.COM

As a Matter of Fact

Your Smartphone Contains Valuable Chemicals

A smartphone contains chemical elements called **rare earth metals** that make the circuitry, speakers, screen, and vibration unit of a smartphone. **These elements consist of scandium, yttrium, and the lanthanide series of elements, found near the bottom of the periodic table.** For example, neodymium is used in magnets that make speakers vibrate to create sound, europium creates a bright red color on the screen, and lanthanum is used in the glass polishing and phone circuitry.

Recycling smartphones is important because it is far cheaper to extract rare earth elements from recycled products than to mine them from the Earth's crust. Also, mining rare earth elements can damage surface vegetation and cause soil erosion, and they generate waste that can contaminate the surrounding air, soil, and groundwater. To find information about recycling electronic products in your state or region, you can go to: **http://www.epa.gov/epawaste/conserve/materials/ecycling/live.htm**

Color Screen
Yttrium
Lanthanum
Praseodymium
Europium
Gadolinium
Terbium
Dysprosium

Glass Polishing
Lanthanum
Cerium
Praseodymium

Vibration Unit
Neodymium
Terbium
Dysprosium

RHONDA SAUNDERS; PHOTOS.COM

Phone Circuitry
Lanthanum
Praseodymium
Neodymium
Gadolinium
Dysprosium

Speakers
Praseodymium
Neodymium
Gadolinium
Terbium
Dysprosium

OPEN FOR DISCUSSION

By Barbara Sitzman and Regis Goode

The Big Bag Battle

"Plastic or Paper?" asks the grocery clerk. How would you answer? Which is best for the environment? Across the country, cities and states are working on legislation to ban plastic bags and charge for paper. What are their concerns?

Paper

Paper bags are stronger, thicker, and can carry more than plastic. **Since they are made from trees, a renewable resource, they are biodegradable.** What's the problem? Lots of trees are needed to make paper: three tons of wood chips yield only one ton of wood pulp! Producing a paper bag requires massive amounts of water, so paper mills are located near rivers and lakes. Also, their discharge releases harmful chemicals. Making paper bags requires more energy and creates more pollution than manufacturing a plastic bags (Table 1). So, are plastic bags better?

Pollution	Chemicals Released	Problem	Environmental Effects
Air Pollution	H_2S, NO_2, SO_2	Acid rain	Lowers water pH
	CO_2	Increased greenhouse effect	Global warming
Water Pollution	Nitrogen and phosphorus compounds	Algal bloom and decomposition	Dead zones
	Cl_2 from bleaching	Chlorinated organics	Toxic to aquatic animals

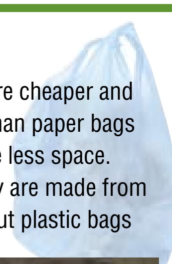
Table 1. Environmental impact of paper bag production

Producing a paper bag requires lots of water and generates pollution.

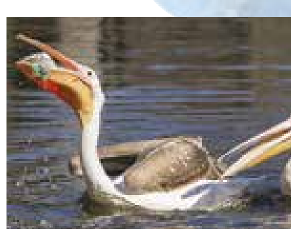
Reusable bags

Considering the problems previously noted, are reusable bags the answer? They can be made of strong, durable material such as canvas. **Reusing them reduces landfill waste and the energy consumed during production, transportation, and recycling.** Almost perfect, right? Not completely! For example, a leak from a meat package collecting in the canvas fibers may provide a safe haven for bacterial growth, especially when left in a warm car. In May 2012, a girls' soccer team in Beaverton, Ore., was sickened by a norovirus traced to their contaminated, reusable team snack bag. Ensuring safety will required special care of reusable bags.

Plastic



What are the advantages of using plastic bags? They are cheaper and more water resistant. They consume fewer resources than paper bags so production costs are less. In the landfill, they require less space. Although produced from a nonrenewable resource, they are made from petroleum fractions that have little commercial value. But plastic bags may not be the answer! **The United States consumes 380 billion bags each year.** Unlike paper, they are not biodegradable; instead, they photo-degrade into tiny plastic pieces that block the gastrointestinal tracts of animals. This particularly affects marine animals that mistake the bags for jellyfish. Plastic bags account for 10% of litter washed up on U.S. shorelines. So is there an alternative?



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What should we do?

To check out regulations in your area, search online for **"National Conference of State Legislatures" and "plastic bag legislation."** Soon, scientific research may come to our rescue. The **Green-Diamond bag company** has developed a process using chitin from discarded crab shells to make their bags microbial resistant. They advertise **"the only triclosan-free, antimicrobial reusable shopping bag".** In the meantime, read more on recycling in the article titled "It's Not Easy Being Green… Or Is It?" on p. 12.

AP-360 / STARS DESIGN GROUP

ICE, Cream... and Chemistry

By Brian Rohrig

There is perhaps no fonder childhood memory than the local ice cream truck driving through the neighborhood, music blaring from its tinny speakers, beckoning all to partake of its frosty delights. But ice cream is not just for kids. **U.S. residents consume 1.5 billion gallons of ice cream each year; that's roughly 5 gallons (19 liters) per person!** The ice cream we all enjoy is the result of years of experimentation involving—you guessed it—*chemistry*!

Air is important!

If you have ever made ice cream, you already know what goes into it, ingredients such as milk, cream, and sugar. But there is one main ingredient that you may not have thought about, probably because you can't see it—*air.*

Why is air so important? If you have ever had a bowl of ice cream melt, and then refroze it and tried to eat it later, it probably did not taste very good. If you set a whole container of ice cream on the table and let it melt, the volume of the ice cream would simply go down. **Air makes up between 30% and 50% of the total volume of ice cream.**

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To get an idea of the effect of air on ice cream, think of whipped cream. If you whip air into cream, you get whipped cream. Whipped cream has a different texture and taste than plain cream. Plain cream tastes sweeter than whipped cream. Just like ice cream without air, pure cream has a sickly, overly sweet taste. This is because the structure of a substance can have a big effect on how it tastes. The structure often controls the rate at which flavor molecules are released into the mouth. The larger the structure (of ice cream, in this case), the longer it takes for flavor molecules to be released. Flavor molecules trigger receptors on the mouth and tongue.

The amount of air added to ice cream is known as overrun. If the volume of ice cream is doubled by adding air, then the overrun is 100%, which is the maximum allowable amount of air that can be added to commercial ice cream. The less expensive brands usually contain more air than the premium brands. One side effect of adding a lot of air to ice cream is that it tends to melt more quickly than ice cream with less air.

The amount of air, known as overrun, in the dish of soft-serve ice cream on the left is 65%, versus 35% on the right.

ELECTRO FREEZE/H.C. DUKE & SON, LLC

The amount of air also has a huge effect on the density of the ice cream. A gallon (3.8 liters) of ice cream must weigh at least 4.5 pounds, making the minimum density 0.54 gram per milliliter (or 540 grams per liter). Better brands have higher densities—up to 0.9 grams per milliliter. The next time you visit a grocery store, compare cheaper and more expensive brands by holding a container in each hand—you should be able to notice a difference. Then read the net weight on the label to confirm your observation. Due to the high fat content of ice cream, however, and because fat is less dense than water, any ice cream will always be less dense than any aqueous solution. Otherwise, you would not be able to make root beer float!

Ice cream is an emul-

sion—a combination of two liquids that do not normally mix together. Instead, one of the liquids is dispersed throughout the other. In ice cream, liquid particles of fat—called fat globules—are spread throughout a mixture of water, sugar, and ice, along with air bubbles (Fig. 1). If you examine ice cream closely, you can see that the structure is porous. A typical air pocket in ice cream will be about one-tenth of a millimeter across. The presence of air means that ice cream is also a foam. Other examples of foams are whipped cream, marshmallows, and meringue (as in lemon meringue pie).

A close look at ice cream shows its porous structure.

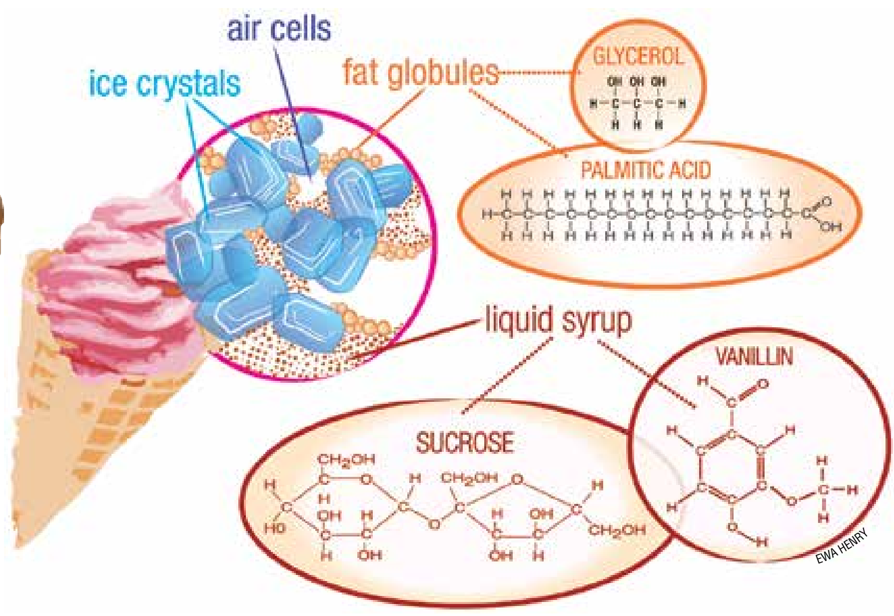

Figure 1. Some of the most common ingredients in ice cream include ice crystals, air, fat globules, sugar (sucrose), and flavoring agents (such as vanillin).

Sugar and fat

Milk naturally contains lactose, or milk sugar, which is not very sweet. Ice cream makers need to add a lot more sugar than you probably realize—usually, sucrose or glucose. Cold tends to numb the taste buds, making them less sensitive. So, more sugar needs to be added to produce the desired effect at the low temperatures at which ice cream is usually served. If you taste ice cream at room temperature, it will taste overly sweet. You may have noticed this same effect with carbonated soft drinks. If consumed warm, they taste sickly sweet. In parts of the world where soft drinks are normally consumed warm, there is less added sugar. If these same soft drinks were served cold, they would not taste sweet enough.

A big reason why ice cream tastes so good is because of its high fat content. Unless it is labeled as light, low-fat, or non-fat ice cream must contain at least 10% fat, and this fat must come from milk. (You cannot use lard when making ice cream!) Before milk is homogenized, a thick layer of cream rises to the top. This cream has a high-fat concentration—up to 50%—and supplies most of the fat in ice cream.

Premium ice creams may have up to 20% fat, which gives it a velvety, rich texture. Reduced-fat ice cream does not taste as good as the real thing, and tends to lack the creamy texture. Although fat is frequently vilified, it has its purpose. Most foods that taste delicious probably contain fat. Fat fills you up, so you don't have to eat as much to feel full.

The problem with using fat as an ingredient in any food is that it does not mix well with a lot of other substances. Fat is nonpolar, meaning positive and negative charges within the fat molecule are equally dispersed. A polar substance, such as water, has separate regions of positive and negative charges—one end of a polar molecule has a partial positive charge, and the other end has a partial negative charge. Polar and nonpolar substances do not mix. Just like oil floats to the top of water, the fat content of ice cream has a tendency to separate out, as well.

Keeping it all together

Because ice cream is an emulsion, you would expect that the fat droplets that are present in the mixture would separate after some time, similar to a bottle of salad dressing in which the oil separates from the rest of the dressing. When you shake a bottle of salad dressing, the two parts come together. But after a few minutes, they begin to separate. That's because the oil droplets interact with one another, a process called coalescence.

In the case of milk, each fat droplet is coated with a layer of milk proteins that prevents the fat droplets from interacting with one another. These milk proteins act as "emulsifiers"—substances that stabilize emulsions and allow the liquid droplets present in the emulsion to remain dispersed, instead of clumping together. Because these milk proteins have a nonpolar side, and because like dissolves like, the nonpolar sides of the proteins are attracted to the nonpolar fat globules. This is good in milk, but not so good in ice cream, in which the fat droplets should coalesce to trap air.

So another emulsifier is added to allow the fat droplets to coalesce. This emulsifier replaces milk proteins on the surface of the fat droplets, leading to a thinner membrane, which is more likely to coalesce during whipping. A common emulsifier is lecithin, found in egg yolks. Lecithin is a generic term that refers to a group of molecules that consist of long chains of fatty acids linked to a glycerol molecule, along with choline and a phosphate group (Fig. 2).

container. Both are derived from seaweed! Without these stabilizers, ice cream might look like a milkshake.

Once you get all of the ingredients together in a mixture, you need to freeze the mixture to form ice cream. The dissolved solutes (mostly sugar) in the liquid portion of the mixture lower its freezing point. A freezing point depression of 1.86 °C occurs for every mole of solute added to 1 kilogram (kg) of water. In other words, if you dissolve one mole of sugar in 1 kg of water, water will no longer freeze at 0 °C, but rather will freeze at –1.86 °C.

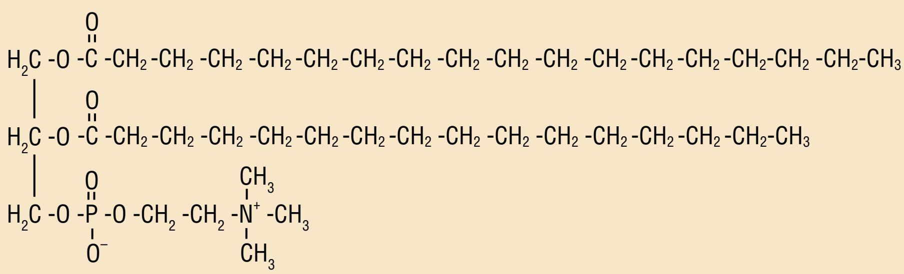

Figure 2. Chemical structure of a type of lecithin called phosphatidylcholine

Lecithin inserts itself between the fat globules, which helps the fat globules to stay together and, as a result, the air bubbles that are present in the mix are trapped by this partially coalesced fat. This adds firmness and texture to the ice cream, enabling it to retain its shape.

Closely related to emulsifiers are stabilizers, which make the texture creamy. Stabilizers have two roles: First, they prevent large crystal formation. In the presence of stabilizers, ice cream contains small ice crystals, which melt more slowly than larger ice crystals, due to the insulating effect of fats surrounding small crystals. Second, emulsifiers act like a sponge by absorbing, and then locking into place, any liquid in the ice cream.

Common stabilizers are proteins, such as gelatin and egg whites. Guar gum, locust bean gum, and xanthan gum can also be used. **Look for carrageenan and sodium alginate on the ingredients' label of your ice cream**

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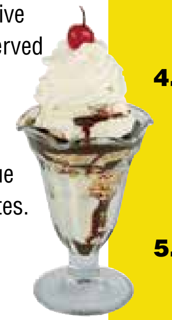
Freezing point depression is a colligative property, meaning that the effect is observed regardless of the specific identity of the solute—all that matters is how many moles are dissolved. A typical batch of ice cream will freeze at –3 °C (27 °F), due to the presence of all the dissolved solutes.



BrAiN FReEZe!!!

MIKE CIESIELSKI

When ice cream touches the roof of your mouth, it may trigger a cold headache. The cause is a dilation of blood vessels in your head located above the roof of your mouth. When this nerve center gets cold, it seems to overreact and tries to heat your brain.

Ice Cream True or False?

Many myths and half-truths are floating around about ice cream. Test your ice cream knowledge by deciding whether each of the following is true or false:

1. **Margaret Thatcher,** former prime minister of the United Kingdom, helped to develop the formula for soft-serve ice cream before she entered politics, while working as a chemist in the food science industry.

2. **Soft-serve ice cream was born on Memorial Day in 1934** when an ice cream truck broke down, and the salesman had to sell his melting ice cream, which was a big hit.
3. Modern-day ice cream was accidentally discovered **in 1782 by Martha Washington,** wife of the first U.S. president, who left a bowl of cream on the back steps of her home one night and, in the morning, found that it had hardened into ice cream.

4. The infamous **Roman emperor Nero** had slaves who would bring ice from the mountains so he could enjoy chilled desserts by pouring fruit juice and honey over the ice.
5. **Ice cream sundaes** were invented in the late 1800s in New York to circumvent a law prohibiting the serving of ice cream on Sunday, hence the name.
6. Eskimo pies were originally called **"I Scream Bars."**
7. **Explorer Marco Polo** was the first person to bring ice cream to the New World, bringing the recipe from China.
8. **The ice cream cone** was invented in 1904, during the St. Louis Exposition in Missouri, when an ice cream vendor ran out of bowls and substituted rolled up waffles instead.
9. The ice cream sandwich was invented by **the Earl of Sandwich** in England.

Types of ice cream

Soft-serve ice cream, frozen custard, and frozen yogurt. What is the difference?

Regular ice cream is typically served at –12 °C, while **soft-serve ice cream** is served at –6 °C. This higher temperature is responsible for a softer product. Soft-serve ice cream, or soft serve, for short, contains less fat and more air than regular ice cream. Soft serve with insufficient air will have a yellowish color. The whiter the soft serve, the better the quality. As ice cream melts, you may have noticed this yellow color, which is simply the actual color of the ingredients used to make it. By adding air and fluffing it up, ice cream is better able to reflect white light, producing the white color. This is because the molecules in ice cream are large enough to reflect visible light (whereas, for example, water molecules are too small to reflect visible light, because the size of a water molecule is smaller than the wavelengths of visible light).

Frozen custard differs from ice cream in that it contains at least 1.4% egg yolks. Egg yolks are made of lecithin, an excellent emulsifier. The result is a product with a smoother, creamier texture. Another difference is that frozen custard contains much less air than ice cream. No air is mixed during its manufacture; instead, air is introduced during mechanical agitation as the frozen custard is being made. It is churned more slowly during its manufacture to minimize the amount of introduced air. Less air leads to a thicker, denser product. Frozen custard is typically made fresh each day in the store. It is frozen quickly to prevent large crystals—of water, lactose, or any added sugar—from forming.

Frozen yogurt is making a huge comeback these days, with self-serve frozen yogurt shops offering a plethora of toppings popping up seemingly on every corner. Frozen yogurt is viewed as a healthier alternative to ice cream, unless you top it off with a generous helping of gummy bears! It contains less fat, but that means you can eat more without feeling full. And to compensate for less fat, often a lot of sugar is added. The biggest difference is that instead of cream, yogurt is added as the primary dairy product. From there, the process is similar to making regular ice cream.

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A recent trend is ice cream made with liquid nitrogen. One shop in San Francisco, Calif., aptly named Smitten Ice Cream, has a viewing area where customers can watch ice cream being made with liquid nitrogen, accompanied by the impressive plume of fog that is released. Liquid nitrogen, which boils at –196 °C, will freeze ice cream almost instantly. Because the ice cream freezes so quickly, the size of the crystals is small, resulting in a creamy texture. And because it boils when it hits the mixture, the ice cream is aerated during the process. The popular Dippin' Dots are also made using liquid nitrogen. It is no exaggeration to say that ice cream made with liquid nitrogen is the coolest ice cream around! CM

ADAM LOWE, COURTESY OF SMITTEN ICE CREAM

Ice cream shops serving desserts made with liquid nitrogen are unique and very popular.

MIKE CIESIELSKI

Look out for the weirdest ice cream flavor: garlic flavor!

Answers to True or False

1. Probably false. While Thatcher did work as a chemist for a company that developed soft-serve ice cream, her actual role in developing the product was likely minimal, if at all.
2. Likely true, but may not be the first.
3. False.
4. Probably true.
5. Possibly true, but there are several other equally compelling stories about to the origin of the sundae.
6. True.
7. Story likely true, but may not be the first.
8. Story likely true, but may not be the first.
9. False. Don't mistake the ice cream sandwich for the actual sandwich, which was invented by the Earl of Sandwich.

Note: If you are concerned about the ambiguity of these answers, now you know why ice cream historians are still arguing about the origins of ice cream!

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Brian Rohrig teaches chemistry at Metro Early College High School in Columbus, Ohio. His most recent *ChemMatters* article, "Hot Peppers: Muy Caliente!" appeared in the December 2013 issue.

BETH NOLTE

Going the Distance

Searching for Sustainable Shoes

By Beth Nolte

I scraped a glob of strawberry off the top of my shoe. Seeds stuck to the laces. The sporty black gym shoes that I usually wore to my office job were getting trashed at the local grocery store, where I work during the weekends. I took the job imagining that I would spend my time admiring the vegetables, reading a book, and occasionally helping a customer. It turns out it is a more demanding job than I imagined! Mostly, I am moving boxes, some of which contain spoiled fruit. Today, it was strawberries. A fat red orb spilled out and landed with a splat of sweet nectar on the top of my shoe.

I need different shoes!

Back at home, I dug out my last pair of old shoes. They were dust-encrusted after three months in India. Too bad. My old shoes felt good, looked cool, and the rubber soles were made from recycled car tires. **They were green shoes both in spirit and color, even though when I bought them two years ago, they were gray.** Even if I could get away with wearing these grassy old ones, I decided to see what else I could find.

My online search for new shoes opened up a portal that I could not close. I saw a glimpse into the world of shoe manufacturing that changed me. There are networks of products and suppliers for each part that goes into making a shoe. And when suppliers use chemicals that end up in the environment, it is difficult to know how they affect the environment—or the footprint (pun intended) of a pair of shoes.

I was fascinated by the concept of "green" shoes, which are designed by using green chemistry, a branch of chemistry that focuses on reducing or eliminating substances that are harmful to human health and the environment.

GREG BOGERT

Green design

I was admiring the PUMA Re-Suedes and, in my cyber-stalking, I read everything about them that the Internet search had to offer. These shoes are made from post-industrial materials resulting from the manufacturing of products such as plasma TVs. **Using recycled materials saves energy consumption and reduces carbon emissions, compared to new materials, according to the company's Web site, puma.com.**

The company has committed to phasing out long-chain fluorinated chemicals from its products and supply chain by 2015. **Long-chain fluorinated chemicals, also called perfluorinated compounds, contain carbon and fluorine atoms bonded together with strong carbon-fluorine bonds.** Perfluorinated compounds are derived from hydrocarbons—chain-like molecules that contain hydrogen and carbon atoms—by replacing all the hydrogen atoms with fluorine atoms. The carbon-fluorine bond is the strongest known single bond, and the presence of fluorine reinforces the carbon-carbon bonds.

Perfluorinated compounds are nonpolar, meaning that electrons are shared equally in the molecule. By contrast, polar molecules, such as water, have an uneven distribution of electrons, which creates regions of positive and negative charges. Because polar and nonpolar molecules do not bind with each other, Perfluorinated compounds are insoluble in water, making shoes and clothes waterproof when it rains.

PUMA

One type of perfluorinated compound that is used to make shoes waterproof is perfluorooctoanesulfonic acid, also called perfluorooctane sulfonate (PFOS) (Fig. 1), a toxic chemical which is released from the shoes into the environment. Then, PFOS moves up the food chain, a process known as bioamplification. Fish typically absorb these chemicals. The bioamplification process starts when small fish eat PFOS. Then larger fish eat these small fish, which increases the amount of PFOS ingested by the larger fish. The concentration of PFOS increases, as predators eat their prey in the food chain.

In the quest to use alternative materials, PUMA created the sole of the Re-Suede from Double-R Rice Rubber, a combination of natural rubber and rice husk waste. Previously, the husks were thrown away, but in the Re-Suedes it acts as a filler, which substitutes a portion of the rubber.

The approximate cost is $70 for a new pair. Before clicking on the "Buy Now" button, I wanted to know how Re-Suedes hold up to the **principles of green chemistry (Table 1)**. These principles were developed by John Warner and Paul Anastas, who are known for their ground-breaking work on designing and manufacturing nonhazardous chemicals to give scientists guidelines for what it means to "think green," that is, to ensure that products are not toxic to human health or the environment. The "principles of green chemistry" (above) list what needs to be considered when designing a "green" product or redesigning an old product in an environmentally friendly way. Consumers can also benefit from knowing whether the products they buy were made with these principles in mind.

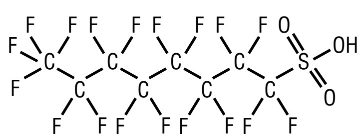

Figure 1. Chemical structure of Perfluorooctane sulfonate (PFOS), an example of a perfluorinated compound

Green Chemistry Principles

1. **Prevent waste:** It is easier to stop waste in the beginning than it is to clean it up.
2. **Atom economy:** Make sure the maximum amount of material used ends up in the final product.
3. **Less hazardous chemical synthesis:** Methods should be designed to use and create little to no toxic products.
4. **Design safe chemicals:** Chemical products are made to have desired function while minimizing toxicity.
5. **Safe solvents and auxiliaries:** Avoid using additional solvents and other agents whenever possible, and use non-toxic chemicals otherwise.
6. **Design for energy efficiency:** Recognize energy impacts and, if possible, use ambient temperature and pressure.
7. **Use renewable feedstock:** Use renewable raw materials, ones that are not depleted.
8. **Reduce derivatives:** Minimize additional steps in chemical synthesis.
9. **Use catalytic reagents instead of stoichiometric reagents:** Catalytic reagents are preferred due to their specificity and the small amount required, whereas stoichiometric reagents generate large amounts of waste.
10. **Design for degradation:** Chemical products should break down into products that are not harmful and do not persist in the environment.
11. **Real-time analysis to prevent pollution:** Monitor and control processes before hazardous substances are formed.
12. **Safer chemistry for accident prevention:** Substances are chosen to minimize potential for chemical accidents, including releases, explosions, and fires.

Green Chemistry Principle	Re-Suedes Design
1. Prevent waste	√
2. Atom economy	?
3. Less hazardous chemical synthesis	√
4. Design safe chemicals	√
5. Safe solvents and auxiliaries	?
6. Design for energy efficiency	√
7. Use renewable feedstock	√
8. Reduce derivatives	?
9. Use catalytic reagents instead of stoichiometric reagents	?
10. Design for degradation	√
11. Real-time analysis to prevent pollution	?
12. Safer chemistry for accident prevention	?

Table 1. How Puma Re-Suede shoes hold up to the principles of green chemistry

I made my checklist. As with any product people buy, there is a lot we don't know about the manufacturing process. Question marks in this case are because the information is not available to consumers. Based on what we know, Re-Suedes meet at least half of the green chemistry principles.

Decision time

All of this information made me wonder whether it was the right time for me to buy a new pair of shoes, such as the PUMA Re-Suedes. I decided I liked my old shoes, and they still have a few more miles in them. The sun was out; a perfect day for washing my grassy greens in a bucket and leaving them out to dry.

Now, my old shoes are almost like new shoes... but better. *CM*

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Beth Nolte is a science writer who lives in Louisville, Ky. Her recent *ChemMatters* article, "Hold the Meat! Meat-Free Food Takes a Seat at the Table," appeared in the December 2011 issue.

It's Not Easy Being Green… Or Is It?

By Michael Tinnesand

Fans await the arrival of various celebrities for a charity gala. Group after group of stars arrive in limousines or luxury sports cars. But then, what's this? One of the well-known stars at the event pulls up in a hybrid car, and soon after, another celebrity shows up in an all-electric car. People in the crowd are observing an evolution of chic—from excessive consumption to one of sustainability. ***Goodbye mink coats and Rolls Royces, say hello to the new and "greener" chic!***

But a more environmentally aware social attitude is not just about celebrity or an appealing lifestyle. It is about decisions we make and the impact those decisions have on the environment. But when we want to get a complete view of the impact a product has on the environment, we need to look at a process called **Life Cycle Analysis (LCA)**. LCA examines every part of the production, use, and disposal of a product. This means looking at the collection and processing of the raw materials, the energy used in the production and use of the product, and the transportation and disposal (or recycling) costs.

MICHAEL TINNESAND

A cup of comfort

Imagine stopping by your favorite coffee shop for a hot beverage. Is it more environmentally friendly to purchase coffee in a disposable paper cup or to bring your own ceramic mug, which can be washed and reused many times? It seems like an easy decision. Bringing your own ceramic mug has to be better than a disposable paper cup, right?

MIKE CIESIELSKI

When we look a little deeper, the choice gets more complicated than it first appears. Let's start with the amount of energy it takes to produce once ceramic mug. **According to one LCA study, it takes 14 megajoules (MJ) of energy to produce one ceramic coffee cup. (A joule is a unit of energy that is equal to 2.39×10^{-4} kilocalories.)** By contrast, it only takes about 0.4 MJ of energy to produce a paper cup. (A Styrofoam cup uses only 0.2 MJ of energy.) This means that considering how much energy it takes to produce a paper cup, you would have to use a ceramic mug 35

The choice gets more complicated than it first appears.

times to even out the difference in the energy to produce it over the paper cup (14MJ/35 = 0.4 MJ).

But there are other factors to consider, such as washing the ceramic mug. Even if the energy per use is decreasing every time you use the mug, you still have to add on the wash energy. Assuming the mug is washed after each use, it would take up to 1,000 uses of the mug to become less than the energy per use of a disposable cup. That would be like using the same mug every day for three years!

In the bag

What does LCA tell us about the option of "paper or plastic" at the grocery store checkout or about bringing a reusable cotton shopping bag? The obvious choice would be that a reusable cotton bag would be more environmentally friendly than one-use plastic or paper bags.

But cotton production has some well-documented environmental issues. First, the cultivation of cotton is fossil fuel-intensive because it takes a great deal of tractor work to prepare fields and harvest the cotton. Worse yet, conventionally grown cotton requires more pesticides than any other crop.

MIKE CIESIELSKI

Also, the production of cotton bags releases more greenhouse gases than that of plastic bags. The production of a typical disposable plastic bag (assuming we only use it once) produces 27 grams of carbon dioxide equivalent per bag, while the production of a cotton bag releases 131 times that amount. A carbon dioxide equivalent is a quantity that describes, for a given mixture of greenhouse gases, the amount of carbon dioxide that would trap the same amount of heat as the gases present in the mixture over a specific time interval—100 years in this case.

PHOTOS.COM, SHUTTERSTOCK

This means that a cotton bag would have to be reused 131 times more to be a greener choice. But what about reusable bags made of polyethylene or polypropylene? These turn out to be better alternatives at only 11 times disposable plastic. Less sturdy low-density polyethylene bags are even better at 4 times. We only gain ecological advantage if we actually use our reusable bags.

All bottled-up

Our last example concerns another consumer choice. Should we choose a disposable plastic bottle, a glass bottle, or an aluminum can when we buy a soft drink or other beverage?

MIKE CIESIELSKI

A recent study measured the total energy to produce each product, greenhouse gas emitted, and solid waste produced. The study compared the containers on the basis of global impact for the number of containers required to each hold 100,000 ounces of beverage. The results are shown in Table 1.

Product	Total Energy (BTU*)	Greenhouse Gas (pounds of carbon dioxide equivalent**)	Solid Waste (pounds)
Plastic bottle	11.0	1,125	302
Glass bottle	16.0	2,766	767
Aluminum can	26.6	4,949	4457

Table 1. Total energy, greenhouse gas emissions, and solid waste created by plastic bottles, glass bottles, and aluminum cans that would each hold 100,000 ounces of beverage. *One BTU (British Thermal Unit) is the amount of heat needed to raise one pound of water by one degree Fahrenheit. **See the main text for the definition of a carbon dioxide equivalent.

In each of the measures, the disposable plastic bottles more favorably impact the environment than either glass or aluminum containers. Glass containers are the heaviest containers of the three. This makes energy and greenhouse emissions larger for glass because heavy containers require more energy to transport and process. Aluminum is light, but the energy required for smelting and forming the aluminum containers adds to their numbers.

A note of caution

We have chosen three examples showing that selecting a more environmentally friendly item is not as obvious when the total life of the product is examined. But this is not to say that every choice for a more sustainable option is other than it seems. LCA and other environmental tools can perhaps give us a better way to make decisions about how we can best produce and consume products.

Another issue that cannot be stated strongly enough is that assessments such as LCA are complex. Trying to evaluate every factor that goes into the environmental impact of a product is complicated. For example, we may dislike the way plastic bags litter our landscape and choose to ban them for that reason. The same might be true for soft-drink containers discarded on the beach. And one sea animal killed by eating a Styrofoam cup might be one too many. So, we may be willing to bear the environmental cost of reducing our use of these products because of other ways they impact our ecosystem. It's a decision that must be made based on all available data and values.

Who knows? Maybe we are even willing to pay the price to have our celebrities keep their limousines. These decisions are all part of how we move toward a sustainable future. *CM*

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The team of engineers hunkers down in the bunker as the countdown begins. A moment later, flames, smoke, and dust explode in a fireball. The blast reverberates even through the bunker walls, which are more than 1-foot thick and are buried under several feet of earth. No matter how many times they witness a blast, the engineers can't help grinning, as the sound fades and the dust settles.

An Explosion of DIAMONDS

By Chris Eboch

An explosion on this remote mountain could mean that engineers are testing hazardous materials, developing new explosives, or training first responders to prepare for a terrorist attack. But that's not what these engineers are doing here. They are making diamonds.

Diamonds are famous for their beauty, rarity, and high cost. Yet much of what the public knows about diamonds is more myth than reality. While quality gemstones can indeed be beautiful, rare, and expensive, diamonds may also look like dust and be used in lab equipment. And they are becoming more common, thanks to several methods for making synthetic diamonds.

What makes diamonds so special? How—and why—are they manufactured in laboratories or mined from the Earth?

PHOTOS.COM, SHUTTERSTOCK

How diamonds are formed

The myths about diamonds start with ideas about how they are made. One common belief is that diamonds are formed from changes in the structure or composition of coal, as pressure compresses coal into diamonds. In fact, this is rarely true. Coal seldom exists at depths greater than 2 miles (3.2 km) below the Earth's surface. Diamonds, on the other hand, are formed under high pressures and temperatures deep below the surface of the Earth. These conditions exist in some parts of the Earth's mantle, where temperatures reach more than 2,000 °F (1,050 °C). These areas are also under enormous pressure from the weight of the overlying rock.

Also, coal comes from decaying plants, while most diamonds are much older than the first plants. Almost every diamond that has been dated was created between the Earth's formation (about 4.6 billion years ago) and about 542 million years ago. In contrast, the earliest land plants did not appear on Earth until about 450 million years ago.

So where does the myth come from? Diamonds come from carbon, and coal contains carbon (and other elements). But the source of diamonds is most likely carbon that was trapped in the Earth's interior when the planet was formed, not coal.

MIKE CIESIELSKI

Elemental carbon may exist in several forms, two of which are graphite—which is used to make pencil lead—and diamond. The form carbon takes depends on several factors, including the pressure and temperature during formation. These forms are called allotropes—different structural modifications of an element in which the atoms of the element are bonded together in a different manner.

The structure of graphite is based on sheets of carbon atoms (Fig. 1). Within each sheet, every carbon atom is bonded to three adjacent carbon atoms. Each carbon atom has four valence electrons, which participate in the formation of chemical bonds. Three of these electrons are used in forming strong covalent bonds with the adjacent atoms in the sheet. The fourth electron is free to wander over the surface of the sheet, making graphite an electrical conductor. Weak attractive forces called van der Waals forces hold the sheets together. Because these forces are weak, the sheets can easily slide past each other, making graphite soft.

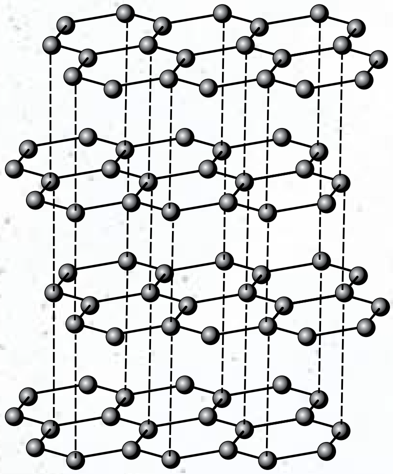


Figure 1. Chemical structure of graphite

In diamonds, each carbon atom is strongly bonded to four adjacent carbon atoms (Fig. 2). The bonds have the same strength in every direction. This makes the resulting material much harder. In fact, diamond is more than 1,000 times harder than graphite and is the hardest known natural substance on Earth.

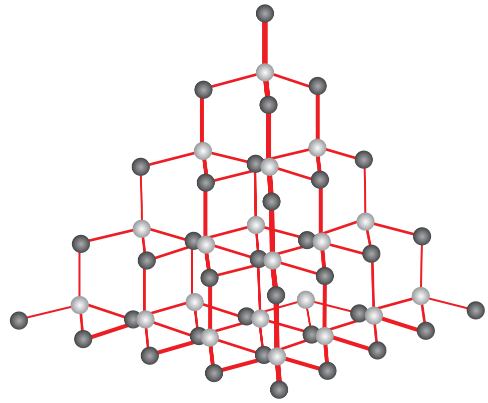
Finding diamonds

Most natural diamonds are formed about 90 miles below the Earth's surface, where the required high temperatures and pressures occur. They are delivered to the Earth's surface during deep-source volcanic eruptions that carry them rapidly—at 20 to 30 miles per hour—to the surface (Fig. 3).

These violent eruptions took place in the distant past and were extremely rare. Yet these eruptions are the source of most of the natural diamonds that people can find on or near the Earth's surface. A few other processes may form natural diamonds, but they are less common, and the resulting diamonds are generally too small for most uses.

DE BEERS DIAMOND COMPANY

Inspectors at the Venetia Diamond Mine, South Africa's largest diamond mine.

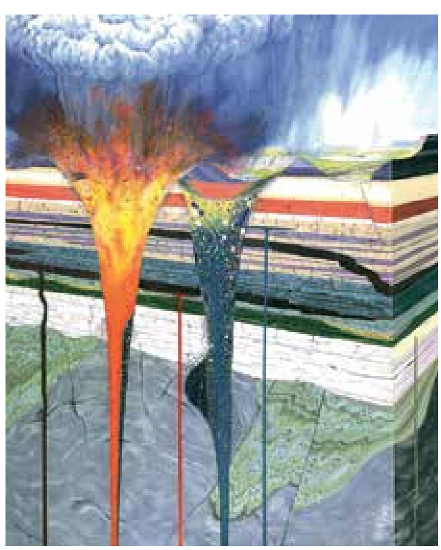


CESAR CAMINERO

Figure 2. Chemical structure of diamond

This means gem-quality diamonds—those used in jewelry—are rare. But gemstone diamonds are more common than many of the other colored gemstones, such as rubies and sapphires. Companies with excellent marketing campaigns and a tight control of the diamond trade have encouraged the myth that diamonds are the most precious of precious gems.

Natural diamonds are found in or near the volcanic pipes that bring the diamonds to the Earth's surface. At Crater of Diamonds State Park in Arkansas, visitors have found diamonds on park grounds. These fields are the eroded top of an ancient volcanic crater that brought the diamonds to the surface. Diamonds can also sometimes be found loose in streams, where they have washed out of the rock. Most of these loose diamonds are small, however, and not of the quality necessary for gemstones.



COURTESY OF DE BEERS MINING COMPANY

Figure 3. Natural diamonds are formed through the explosion of volcanoes that contain a rock called kimberlite. As shown in this artist's impression, such volcanoes contain vertical structures, known as kimberlite pipes that are the most important source of mined diamonds.

An alternative to nature

Most natural diamonds are excavated in mining operations. Diamond-mining is strenuous, dangerous, and labor-intensive. It typically takes 5 tons to 10 tons of ore to produce one carat of "diamond rough," or diamond in its natural state. Of that diamond rough, no more than 15% is likely to be of high enough quality for gemstones. Even less is large enough to cut into a one-carat stone, because rough stone will lose much of its weight when cut into a gem. Carat refers to the unit of measurement used to describe the weight of a gemstone and equals 200 milligrams (mg), or one-fifth of a gram. Stones greater than 1 carat are rare, and therefore more expensive than smaller stones.

Because of the difficulties in mining diamonds, some people believe that artificial diamonds would be a better substitute for natural ones. The challenge is making artificial diamonds that are large enough to be used as gemstones.

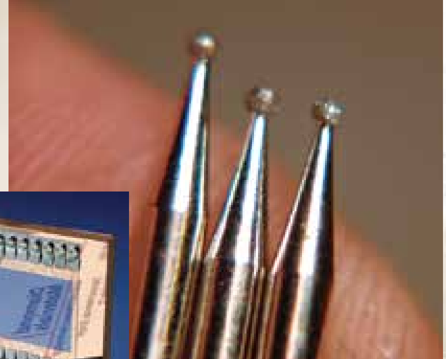
COURTESY OF CRATER OF DIAMONDS STATE PARK

Natural diamonds

Several companies have found ways to manufacture diamonds that are chemically identical to diamonds mined from the Earth. One method uses large presses to provide the necessary high pressure and high temperature. A carbon material is fed into the presses along with a catalyst. The press applies pressure and temperature to mimic the conditions that form natural diamonds. This process may take several days or weeks. The resulting crystals may be several carats in size, big enough to cut a finished diamond of one or two carats. These synthetic diamonds can be large enough to be used as gemstones in jewelry, although they are still not commonly used for that purpose.

Manufactured diamonds are mainly used for industrial applications. Because they are hard and resistant to wear, manufactured diamonds (but also natural ones) are used to edge cutting tools, including surgical knives. They are also chemically inert, not reacting to most acids or alkali. This makes diamonds useful in harsh environments. Their insulating properties work well in electronics. Diamonds are also used in lenses, lasers, and infrared and X-ray windows. For many of these uses, diamonds do not need to be large or of gemstone quality.

DIAMOND-MATERIALS.COM

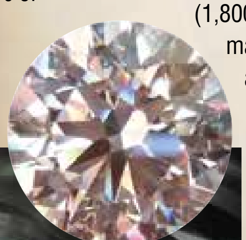


GEMROCKAUCTIONS.COM

Diamond-tipped drill bits (above) and X-ray fluorescence monitor (left) are examples of products that use artificial diamonds.

Another method of producing diamonds in a laboratory uses chemical vapor deposition (CVD). CVD is a chemical process used to produce high-purity, high-performance solid materials. The process is often used in the semiconductor industry to produce thin films.

To make diamonds, methane gas is mixed with hydrogen gas at a temperature of 1,300 °F to 1,800 °F (700 °C to 1,000 °C). The mixture is put into a partial vacuum. The pressure is relatively low, which would normally produce graphite or another form of carbon besides diamonds. But in a CVD growth chamber, some of the hydrogen is converted to atomic hydrogen through methods such as the application of microwave energy, an electric discharge, or hot filaments. Hydrogen atoms are highly reactive, and they react with methane to form highly reactive molecules made of carbon and hydrogen atoms. These molecules attach themselves to diamond seed crystals present in the growth chamber, and in the process, they give up their hydrogen. This causes the seed crystals to grow and form bigger diamonds that are a few millimeters, or even centimeters, in size.



COURTESY OF DALLAS EQUIPMENT SALES, DALLAS, TEXAS

A high-pressure high-temperature diamond crystal growth chamber is used to make synthetic diamonds, such as the one shown above.

The CVD process can form wafers or films of pure diamond. Because diamonds are so hard, the diamond sheets are cut into their final shapes by lasers. This material can be used in many industrial processes.

Exploding diamonds!

A third method of diamond manufacturing is more dramatic, although it still uses heat and pressure. Workers put a 4,000-pound (1,800-kg) steel tube containing diamond-making raw material—the specifics are an industry secret—into a 14-foot-tall (4.25 m) steel culvert. They pack about 9,000 pounds (4,000 kg) of explosives around the pipe. The blast squeezes the pipe and provides the heat and the pressure to change carbon into diamonds.

The explosion leaves a crater, but the pipe survives. Inside is a gray powder that is actually tiny industrial diamonds. This procedure is more expensive than other methods of making diamonds, but the finished product is especially good for grinding or polishing. The diamond powder is used in the polishing of diodes and other high-tech materials. This process was featured on the Discovery Channel show *Mythbusters* during season seven, when the actors tried to make diamonds.

One group that has executed this process is the **Energetic Materials Research and Testing Center (EMRTEC)**, a research division of the New Mexico Institute of Mining and Technology. "This process can produce a tremendous amount of diamond powder in milliseconds," says Graham Walsh, department head of the Chemistry Laboratories at EMRTEC.

Creating diamonds through explosives has its limitations. "These diamonds produced are very small because they are squeezed to that pressure for a very short period of time," Walsh says. "Also, we can't allow the diamonds to stay too hot for too long. If the diamonds are allowed to cool slowly after being produced, a large percentage of these diamonds will simply revert back to graphite."

The use of explosives may be the most exciting way of making diamonds, but the end result is less impressive than the sparkling gems in the jewelry store. According to Walsh, "On the atomic scale, they are the same as natural diamonds. They are carbon in the diamond phase. Visually, they're about as far removed from what we think of as diamonds as you can get. They are small, aren't clear, and don't have cleaved edges. They look like grey dirt."

PHOTOS.COM

Although it may not look pretty, this so-called gray dirt can be used for important industrial and scientific purposes. Some people argue about whether manufactured diamonds are "true" diamonds. Those who wear diamond jewelry may care about such things. For industrial uses, manufactured diamonds are as good as natural ones, and in some cases better. *CM*

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From WASTE to ENERGY Thanks to METHANE

By Daryl Ramai

What if you decided to save your food scraps and store them in an underground tank? And what if, in return, you were rewarded with energy? This energy would light your house, be used to cook food, provide heat, and even fuel your car. And the best part—it would all be free and good for the environment!

Today, food waste, human sewage, and animal dung are providing a relatively new source of energy. When this organic matter is mixed with certain soil bacteria, the bacteria convert it into various gases, including methane. The methane is collected, distributed to homes and other buildings, and burned to produce energy.

Around the world, especially in developing countries, such as India, China, and some African countries, using methane to produce energy provides a cleaner alternative than burning wood— a major cause of respiratory and eye disease. Also, because methane contributes to global climate change, using it to produce energy instead of letting it linger in the atmosphere may help reduce the effects of climate change.

COURTESY OF WWW.ASHDEN.ORG

Spoiled fruit, leftover food, and other organic matter are used in this biogas plant in the city of Pune, India.

In the United States, methane is commonly used for electricity generation and home heating, but it is mostly extracted from natural gas, not from food waste and sewage. By contrast, in developing countries and in Europe, it is having a significant impact on people's lives.

How it works

When food scraps, human waste, and animal dung are combined with bacteria, under anaerobic conditions—meaning without oxygen—several gases, such as methane, carbon dioxide, hydrogen sulfide, and nitrogen are produced. This gas mixture is called biogas ("bio" refers to "living" matter). It is mainly composed of methane, which makes up 50% to 80% by volume, and carbon dioxide, which makes up 20% to 50% by volume, depending on the source of organic matter and the conditions of degradation.

Food scraps and human and animal waste—collectively called biological waste—are made up of proteins, carbohydrates, and fats (or lipids). These are examples of natural polymers, large molecules composed of many repeated building blocks, known as monomers.

When they are mixed with methane-producing bacteria—usually present in soil and animal dung—these proteins, carbohydrates, and lipids are broken down into their building blocks, which are, respectively, amino acids, sugars, and fatty acids. These smaller molecules are generated through a chemical reaction called hydrolysis that adds water molecules to the bonds that connect amino acids in proteins, sugars in carbohydrates, and fatty acids in lipids.

The methane-converting bacteria further break down the amino acids, sugars, and fatty acids into organic molecules, which undergo a series of chemical reactions that ultimately lead to biogas, among other final products (Fig. 1).

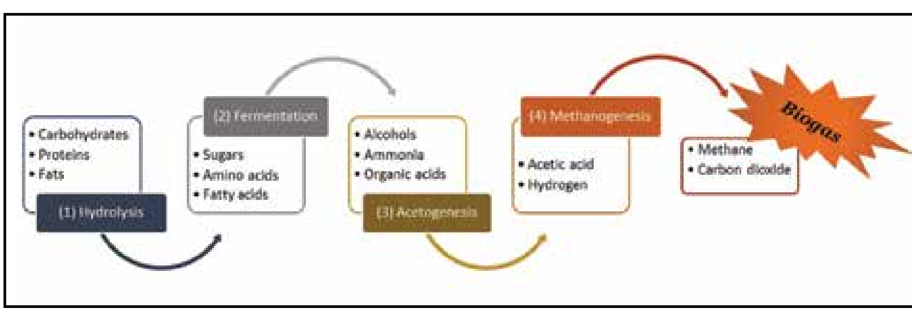


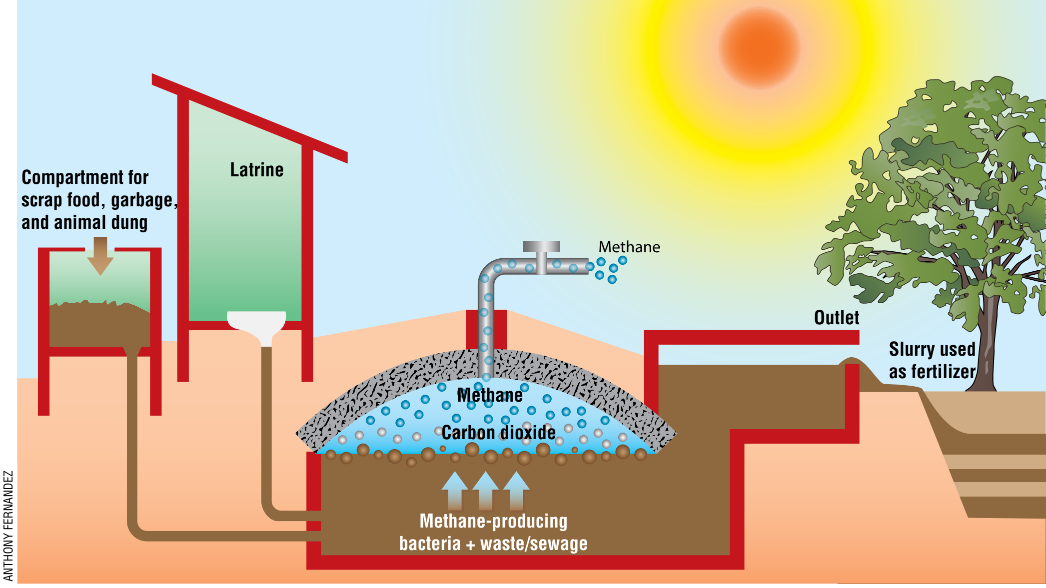
Figure 1. Biological waste (food scraps, human waste, and/or animal waste) is mostly composed of proteins, carbohydrates, and fats that are naturally broken down in four steps to a mixture of methane, carbon dioxide, and small amounts of other gases. The four steps are: (a) hydrolysis, in which the proteins, carbohydrates, and fats are converted into amino acids, sugars, and fatty acids, respectively; (b) fermentation, where these small chain molecules are converted into alcohol, ammonia, and organic acids such as butyric and propionic acid; (c) acetogenesis, where these products are converted into acetic acid and hydrogen; and (d) methanogenesis, where acetic acid is converted into methane. The biogas (methane and carbon dioxide) is collected, and methane is extracted to be used as a source of energy.

The biogas is eventually stored at a nearby processing plant to be "cleaned," so that contaminants such as carbon dioxide and hydrogen sulfide are removed. The methane gas is collected and burned in the presence of oxygen, a process called combustion that results in carbon dioxide, water, and heat:

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) + \text{heat}$$

This heat can be produced directly on a gas stove by burning methane out of the burners or in a boiler used for heating a home. Alternatively, methane can be burned in a power plant, and the resulting heat can be used to spin an energy-generating turbine to produce electricity.

Burning biogas methane generates carbon dioxide, which is a major contributor to climate change. **So it may not appear that biogas methane is better for the environment than the burning of fossil fuels**—the main source of man-made greenhouse gases. In reality, methane produced from food scraps and other plant matter is "carbon-neutral," meaning that the amount of carbon dioxide released when the methane is burned is the same as the amount of carbon dioxide taken in by plants to grow. So, these two effects—the burning of plant matter and the use of carbon dioxide by plants to grow—cancel each other out, resulting in no net increase of carbon dioxide in the atmosphere.



ANTHONY FERNANDEZ

Figure 2. A methane-generating unit is made up of a collecting tank, connections for toilets or latrines, and a pipe that releases the produced methane.

Solving sanitation and energy issues in Nigeria

In the slums of Lagos, Nigeria, many of the pipes that carry drinking water to residents go through lagoons intended for sewage collection. If there are any cracks or punctures within these water pipes, disease-causing germs from sewage may enter the pipes and cause illness in people who drink this water.

In an attempt to solve this sanitation issue, Olatunbosun Obayomi, a microbiologist and inventor, found a solution that reduces harmful pathogens and provides free energy. Instead of an expensive overhaul of the waste system and water pipes, he recommended improving household septic tanks to treat waste and generate energy as a result.

His idea was simple: Remove oxygen from the septic tanks! In the presence of oxygen, disease-causing germs present in feces and other sewage reproduce and spread. These germs include *Escherichia Coli, Cryptosporidium*, and enteroviruses, all of which can be found in both human and animal feces. If these germs end up in the water, then people who drink it may become sick.

But in the absence of oxygen, much of these disease-causing germs die, and when feces and other sewage are combined with methane-producing bacteria, these bacteria decompose sewage to produce biogas, which can then be used.

PHOTOS COURTESY OF OLATUNBOSUN OBAYOMI

(Top) Microbiolgist Olatunbosun Obayomi invented a solution that reduces harmful pathogens and provides free energy. (Above) Sewage is collected and recycled into usable energy.

To make it work, a septic tank is reinforced with wire mesh and several coats of cement. When the cement dries, it seals any cracks and prevents oxygen from coming inside the tank. The tank is then placed into the soil and is directly connected to toilets (Fig. 2). This connection allows waste from the toilets to flow into the tank, where waste is collected and degraded by methane-producing bacteria.

A separate compartment may be added next to the tank to collect food scraps, animal dung, and other household refuse. A pipe emerges from the septic tank above the ground carrying both methane and carbon dioxide (Fig. 2). Methane and carbon dioxide can be separated because of their different densities. **One mole of methane has a mass of 16 grams, and one mole of carbon dioxide has a mass of 44 grams, so methane is about three times lighter than carbon dioxide.** As a result, it will settle at the roof of the tank, above carbon dioxide. So placing the pipe at the surface opening of the tank ensures that most of the gas that exits is methane. Local residents can then use methane gas to fuel cooking stoves and boil water.

The immediate benefit of methane is that it replaces other fuels for cooking, mostly wood, which is often in short supply. **The use of methane as a source of energy also reduces indoor air pollution because it burns without releasing pollutants.** This prevents people from breathing wood smoke, which is responsible for an estimated 1.6 million deaths each year.

COURTESY OF WWW.ASHDEN.ORG

Biogas replaces wood and provides a clean cooking fuel, as in this home in Thunilsina, Nepal.

Energy from toilets in India

In India, human waste is also used to produce methane, which can then become a source of energy. Among the 1.2 billion people who live in India, millions do not have access to hygienic latrines or toilets, so many revert to relieving themselves in public, which facilitates the spread of disease-causing germs. A study, conducted by the Indian government and released in 2012, showed that while 69% of Indians had access to a toilet, only 33% actually used it.

PHOTO JULIA LITTMANN

(Above) Composted human manure for agriculture is hygienic, odorless, and nutritious for plants.

COURTESY OF BOPDESIGNER.COM

Ecosan toilets in Musiri, India. The left side collects feces, and the right side collects hjurine.

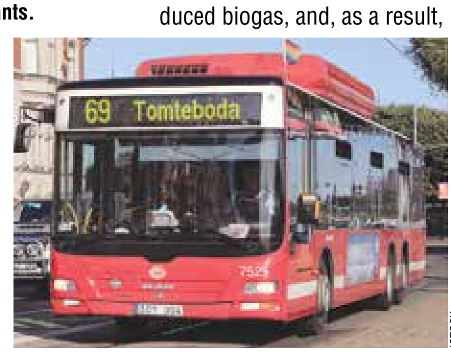
To help solve this problem, the United Nations and a local non-governmental organization (NGO) launched a program to educate people about the role of methane as a source of energy. Communities were taught how methane could be produced from sewage and how it could be used to produce free energy. To help get families started, the program gave $100 to each household to help build a toilet-biogas unit of their own.

As a result, more than 5,000 families in West Bengal signed up. Thanks to these toilet-biogas units, approximately 20 tons of methane gas is being produced each day from waste alone in West Bengal. The United Nations also provides additional money—that acts as carbon credit rewards—to families that produce more than a certain amount of methane. These rewards help sustain the program because families can use the money to repair and upkeep the toilet-biogas unit.

In other parts of India, the Indian government has partnered with another local NGO to build more than 200 toilet-biogas units attached to toilets throughout many Indian cities. These public facilities are being used by thousands of people each day, helping not only to collect sewage but, most important, to generate electricity. In fact, the largest toilet and bath complex in India is made up of 120 toilets and 108 bathing cubicles, and it is used by 7,000 people per day!

Energy Independence in Sweden

Kristianstad, a small city in Sweden, uses no oil, coal, natural gas, or diesel. The city is home to 80,000 people who endure a harsh winter climate. Municipal cars, buses, and trucks run only on state-produced biogas, and, as a result, the city does not need to purchase nearly half a million gallons of oil, coal, and natural gas each year. Kristianstad has completely reversed its dependence on natural gas and oil within a period of 20 years.



ISTOCK

All municipal transportation in Kristianstad, Sweden, runs on state-produced biogas.

"Biogas is a much more secure energy supply," says Lennart Erfors, the engineer who oversees Kristianstad's transition to biogas. "We didn't want to buy oil anymore from the Middle East or Norway."

In a region where farming and food processing are central to the local economy, Kristianstad produces biogas from a hodgepodge of ingredients, such as potato peels, manure, used cooking oil, stale cookies, and pig intestines. These raw materials are combined with methane-producing bacteria and undergo chemical transformations that convert them into biogas. Methane is then extracted from biogas, and it is burned to create heat and electricity or refined as a fuel for cars.

Unlike the septic tanks in Nigeria and biogas units in India, the biogas plant used in Kristianstad required major financial investments to be able to generate energy for the entire city. The entire system initially cost $144 million, but the payback is coming slowly. The city now spends about $3.2 million each year to heat its municipal buildings by using biogas rather than $7 million it would have spent if it relied on oil, natural gas, and coal.

Biogas powering your home?

As more efficient ways for collecting and processing biogas are developed, countries throughout the world may further invest in setting up biogas technology. For example, landfills are a source of biogas in the United States. Currently, 520 U.S. landfills collect methane and convert it into energy, producing enough energy to power 700,000 homes. That is more than enough energy to light all the houses in the city of San Francisco!

Even though biogas will probably not replace fossil fuels anytime soon, it is a great way to produce energy in an environmentally friendly way. Maybe one day, engineers will develop individual units for us to collect and use biogas in our homes. Using waste or trash, we could extract energy to power our homes, fuel our cars, and cut our energy bills. Truly, what might be one person's waste could be someone else's source of energy! *CM*

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Project SEED, established in 1968, provides economically disadvantaged high school students the opportunity to experience a career in chemistry-related sciences. The program places students in academic, industrial, or governmental laboratories for 8 to 10 weeks during the summer to engage in hands-on science research projects with volunteer scientists. **Project SEED** students receive a stipend of $2,500 for their first summer.

Project SEED alumni are eligible to apply for a first-year non-renewable college scholarship. The scholarships are intended to assist former **Project SEED** participants in their transition from high school to college. The scholarships are designed for students who will major in a chemical science field, such as chemistry, chemical engineering, biochemistry, or materials science.

American Chemical Society Project SEED

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