Contextual Chemistry

A SPOTLIGHT ON ISSUES FACING OUR MODERN SOCIETY

Green Chemistry

Over the past couple of decades there has been a growing effort among industries, governmental agencies, and universities to develop technologies that allow materials to be manufactured with reduced or no negative environmental impacts. This is an area of research known as *green chemistry*. To ensure implementation, green chemistry technologies are also designed to be cost competitive and profitable.

Green chemistry applied to the manufacture of materials follows a set of high standards, as outlined here:

1. The raw materials used in the manufacturing process should be sustainably renewable (such as from agriculture) rather than depleting (such as from fossil fuels).
2. Waste products from the manufacturing process should be minimized. Any waste products should be either recycled or rendered environmentally safe.
3. The manufacturing process should be energy efficient. For example, chemical reactions that run at easy-to-attain ambient temperatures and pressures are most desirable. Also, the fewer steps there are to a manufacturing process, the better. Energy can also be saved by using catalysts and by monitoring the manufacturing process carefully to ensure optimal operating conditions.
4. The manufacturing process should minimize hazards. This can be accomplished by choosing chemical reactions that involve fewer toxic chemicals and are not explosive.
5. The desired final products of the manufacturing process should have little or no toxicity and be recyclable. Furthermore, the materials of these products should degrade to innocuous substances after use and not accumulate in the environment.

To illustrate the power and potential of green chemistry, it is useful to look into a few of the growing number of green chemistry projects. To learn about many other projects, be sure to visit either www.epa.gov/greenchemistry or www.acs.org/greenchemistry.

Renewable Toner

biorez®

cleaner, greener toner solution

Laser printers and copiers consume about 400 million pounds of toner each year in the United States. Most of this toner is made from nonrenewable petroleum. This toner is also not easily de-inked from the paper, which means expensive and harsh chemicals are needed for recycling. As a green chemistry alternative, the Battelle Institute (www.Battelle.org) oversaw the development of a high-quality toner made from soybeans. Much less energy is required to create this soy-based toner, which is made from a renewable resource. Furthermore, soy-based toner is easily de-inked from paper, thereby simplifying the recycling process.

Benign Pesticides

As described in Chapter 15, we rely on pesticides to protect our crops. Many modern pesticides, however, are harmful to a broad range of species, including beneficial insects, such as those that pollinate. A number of these pesticides also persist in the environment, where they are taken up into the food chain. To counter these disadvantages, scientists at Dow AgroSciences (www.dowagro.com) have been able to produce pesticides that are specific to the nervous system of certain detrimental insects. As a result, toxicity

to other species, including mammals, is many times lower than that of traditional pesticides. Furthermore, the starting materials for the synthesis of these pesticides are created from fermentation broths. In other words, the starting materials are grown much like a yogurt culture. Also, due in part to their natural origin, these pesticides decompose well, so that they do not persist in the environment.

Affordable Hydrogen Peroxide

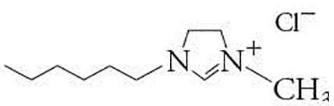
Almost everyone is familiar with disinfecting solutions of hydrogen peroxide, H_2O_2, available from the local drugstore. What most people don't know is that the manufacture of this simple molecule on a large scale is costly, dangerous, and involves numerous steps. This is unfortunate, because H_2O_2 is an effective and environmentally friendly oxidizing agent that would be used extensively by industries if not for its high cost (see Chapter 11). Instead, companies turn to other oxidizing agents, such as chlorine. Although cheaper, chlorine tends to produce highly toxic by-products, such as dioxins. Using nanotechnology, chemists at Headwaters Technology (www.htigrp.com) have recently designed catalysts that allow the efficient and safe production of H_2O_2 in a single step directly from hydrogen, H_2, and oxygen, O_2 (see Section 3.8). Cheaper and readily available H_2O_2 is good news for the profit margins of the chemical industry

as well as for the environment, where H_2O_2 simply decomposes to water (H_2O) and oxygen.

Verstile Ionic Liquids

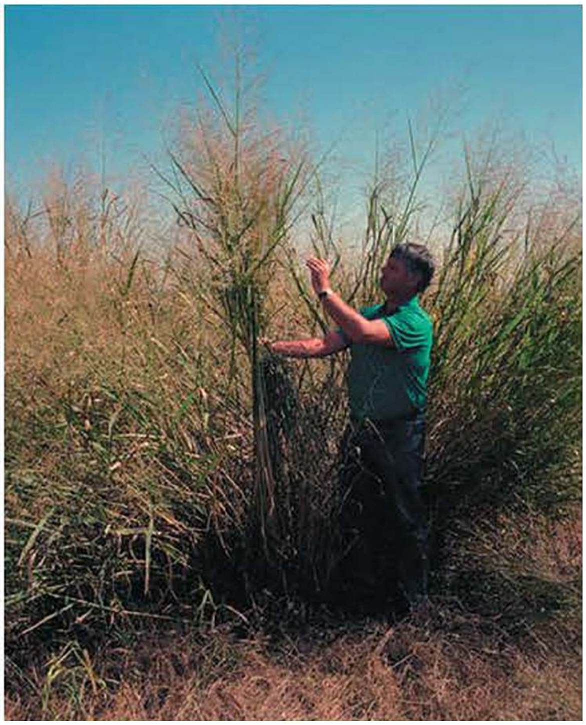
Salts, such as sodium chloride, NaCl, are commonly solids at room temperature. These salts can be transformed into a liquid solution by adding water. There are some salts, however, that are already liquids at room temperature—no water needed! These *ionic liquids* have attracted much attention over the past couple of decades for their many unusual properties and potential applications, especially when it comes to green chemistry.

Many ionic liquids are organic compounds, which means it is easy to modify their properties by tweaking their chemical structures (see Chapter 12). An ionic liquid made of the following compound, for example, has been found to have great potency against the polymer coats, called biofilms, that colonies of bacteria build around themselves for protection. Biofilms are a major problem in hospitals. They also foul the hulls of ships and pipes in industrial machinery. In these situations, biofilms are treated with harsh chemicals. The ionic liquids offer a potentially more effective and environmentally friendly alternative.



▲ 1-hexyl-3-methyllimidazolium chloride

Very exciting is the fact that certain ionic liquids are able to dissolve cellulose, which is, by far, the most abundant and renewable material and energy resource on this planet. As discussed in Chapter 13, Cellulose is the structural biopolymer of plants. Strands of cellulose bind very tightly to each other, which is good for the wood we use to build our houses or the cotton in our clothes. When the cellulose is dissolved in ionic liquids, however, this tight binding relaxes, allowing the separation of individual strands. Separated strands of cellulose can then be easily broken down into sugars that can be fermented into ethanol. (Ethanol from such sources is known as cellulosic ethanol.) They can also serve as a starting material for nonpetroleum-based polymers. Both these applications would help move us away from our dependence upon nonrenewable and greenhouse gas-emitting petroleum.



▲ Switchgrass is an efficient source of cellulose in that it grows year round in many environments and never needs replanting.

C O N C E P T **C H E C K**

How can we be sure that green chemistry technology will get implemented by industries?

WAS THIS YOUR ANSWER? Green chemistry technology is good for the pocketbooks of the industries that implement this technology as well as for the environment.

Think and Discuss

1. Specify which of the principles of green chemistry are illustrated by the example of affordable hydrogen peroxide.
2. To what extent should green chemistry technologies be exported to developing nations? Why?
3. As a consumer, what can you do to support green chemistry?
4. There is now much research being dedicated to the transformation of ever-abundant and renewable cellulose into biofuels and bioplastics. Why wasn't this research started in earnest during the 1960s, which was a decade of much environmental awakening?
5. About 40 percent of all our solid waste sent to landfills consists of cellulose-containing products, such as paper, cardboard, and packaging. Might our landfills one day be considered a valuable source of cellulosic ethanol?