

YOUR WORLD

Biotechnology & You

A magazine of biotechnology applications in healthcare, agriculture, the environment, and industry.

bi Biotechnology
INSTITUTE

Volume 13, Issue No. 2



Industrial and Environmental Biotechnology



Main Points

We're pleased to bring you the spring issue of *Your World* magazine: Industrial and Environmental Biotechnology. New and exciting career opportunities are developing as the biotechnology industry finds ways to manufacture and produce more eco-friendly products and materials for you, the consumer. Read about the efforts and strides being made and how industry and the environment are benefiting from this progress. Imagine yourself in a career where you can take an active role in

- Finding faster, safer, cleaner ways to manufacture everyday products.
- Finding renewable sources for energy.
- Cleaning up and protecting the environment.
- Using computers to find ways to put data to practical use.

Discover the possibilities!

Paul A. Hanle, President
Biotechnology Institute



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YOUR WORLD

Biotechnology & You

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Biotechnology Institute

The Biotechnology Institute is an independent, national, nonprofit organization dedicated to education and research about the present and future impact of biotechnology. Our mission is to engage, excite, and educate the public, particularly young people, about biotechnology and its immense potential for solving human health, food, and environmental problems. Published biannually, *Your World* is the premier biotechnology publication for 7th- to 12th-grade students. Each issue provides an in-depth exploration of a particular biotechnology topic by looking at the science of biotechnology and its practical applications in health care, agriculture, the environment, and industry. Please contact the Biotechnology Institute for information on subscriptions (individual, teacher, or library sets). Some back issues are available.

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On the cover

Clockwise: Bioengineered yeast and corn are used in food; NatureWorks factory in Nebraska; fructose-6-phosphate molecule; waste-degrading bacteria in *bacilli* (rod-shaped) and *cocci* (spherical) forms (SciMAT/Photo Researchers, Inc.); plastic container made of polylactide.

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Industrial-Strength

Henry's typical morning: He eats a bowl of cornflakes while Sarah, his sister, scans the headlines and his dad starts the laundry. Meanwhile, his mother gives antibiotics to the baby and vitamins to everyone else to keep them healthy. When they see the school bus roll up, Henry and Sarah will dash aboard.



©2004 Bryan Leister

Nature inspires biotechnology's improvements in production and variety of goods. *Counterclockwise from hand:* Cornflakes, a spider's silk-spinning glands, oil-eating *Pseudomonas* microbes, barnacles, corn, sea sponges, diatom.

Biotechnology



The scenario above could easily be from 20 years ago as this morning.

But today, Henry's clothes are made with three kinds of enzymes, and his cornflakes contain bioengineered corn, which requires less pesticide to grow than conventional corn.

Genetically engineered bacteria might have helped process the paper the news is printed on, greatly reducing

environmental pollution. Most laundry detergent contains enzymes to get out tough stains, and specially selected and designed bacteria can help manufacture some vitamins and antibiotics, replacing laborious and expensive chemical synthesis. And the school bus may someday start running on "biofuel" harvested by microbes from agricultural waste.

All these advances come through biotechnology. Many more will be available soon, from designer clothes made from corn to medical devices made by microbes.

Biotechnology is the use and modification of living organisms or their products for commercial purposes. **Industrial biotechnology** uses and changes living organisms to aid in manufacturing. Everyone's family—including yours—is already benefiting from industrial biotech.

Environmental biotechnology helps clean up the wastes traditional manufacturing methods produce (see "Clean Sweep"). Scientists can inject microbes into the ground to clean up or deactivate groundwater pollu-

tion. This process, called **bioremediation**, modifies bacteria that naturally break down toxins so we can clean up chemical spills, waste dumps, and even radioactive waste sites faster and more efficiently than without their help.

But even these uses will pale when compared with developments likely to come to pass in the next decade or two.

⊙ Spider silk is stronger than steel, and unlike nylon, is not made of fossil fuels. One company has made it possible for goats to express a spider silk protein in their milk. The protein is then extracted to manufacture "BioSteel" fibers, which the company hopes to use in medical sutures (stitches), bullet-proof vests, and other products.

⊙ Barnacles produce a superstrong glue that holds them tightly to rocks. Unlike most other glues, it dries underwater.

Barnacle-derived glues may find uses in sealing teeth against cavities or mending broken bones.

⊙ Sea sponges make fibers that carry light just like today's high-tech fiberoptic cables, only they don't break as easily. Can these fibers be used to make the next generation of cables?

⊙ The genetic secrets behind the highly intricate patterns produced by microscopic sea creatures called diatoms might be useful for micromanufacturing computer chips, medical devices, and other complex structures.

⊙ A wealth of energy is locked up in agricultural waste, such as manure and corn stalks. By treating the stalks with enzymes such as cellulase, they can be broken down into simple sugars. Researchers hope to develop faster, tougher, and more efficient enzymes, producing sugars that will be the raw materials for chemicals currently made from oil, including synthetic fibers and many plastics. Most exciting is the potential for creating biofuels—plant-derived fuels that will power the vehicles of the next decade, including the yellow school bus Henry's children will ride.

Combining biotechnology with building or manipulating matter at a molecular level—resulting in **nanobiotechnology**—offers the potential of extremely clean, precise manufacturing at a molecular level.

Industrial biotechnology is poised to change the way hundreds of things are manufactured and to do so with less damage to the environment than today's technologies. So read on to find out how industrial biotechnology is becoming more and more a part of your world.

—Richard Robinson



How many common products are already affected by industrial biotech?

Home Sweet Biotech

Quick—name a product of biotechnology. Did a food or perhaps a medicine come to mind? Those are good answers, but that’s only the tip of the iceberg. Every day you use, eat, or wear something made with biotechnology. Let’s start in your closet.

The clothing industry puts biotech to work in a lot of ways. Stonewashed jeans, for instance, involve several biotech processes (see sidebar). To prevent thread from breaking as it is woven, it’s first passed through a starchy paste, a step called “sizing.” The starch must be removed from the fabric before it can be dyed, printed, or processed further, which used to be done by washing the material with strong acids. Now textile mills can use a safer

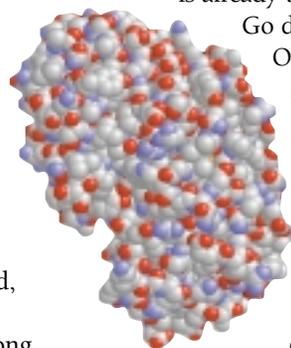
alternative, a solution of amylase enzymes produced by cultured bacteria.

The sneakers under your bed? The leather industry is one of many that use enzymes extensively. Biocatalysts similar to enzymes found in saliva can turn animal hide into leather while producing half as much pollution as chemical tanning. Enzymes are also used to make leather supple, glossy, or suede. Approximately 60 percent of the raw material winds up as waste, and biotechnology is already tackling the job of reducing that.

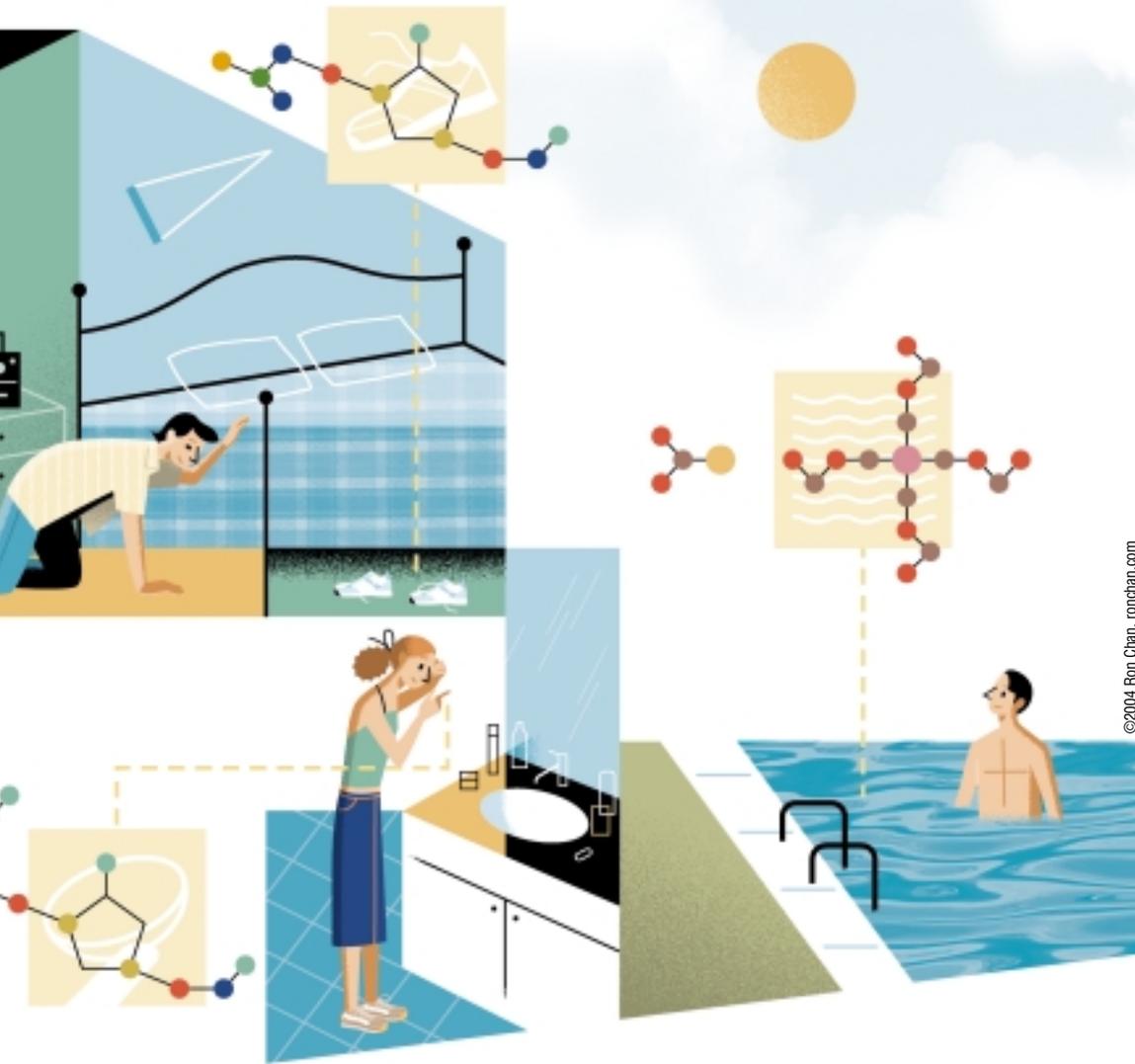
Go down the hall to the bathroom.

Odds are, your contact lens cleaner, shampoo, and cosmetics all contain proteins created by fermenting microorganisms.

You hear the washing machine running as you head toward the kitchen. Years ago enzymes replaced polluting phosphates in laundry detergents. Biotech-derived enzymes also remove stains and improve detergents’ perfor-



Xylanase Molecule



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mance in mineral-rich “hard” water. Clothes can be washed in lower temperatures—saving energy—and with mixtures that are gentler on the fabric and the environment.

In the kitchen, you find the sink clogged. Yuck! But you can use a drain cleaner containing enzymes or whole organisms that break down protein, fats, and greases.

Feel like making a sandwich? Your bread stays fresh longer because an anti-staling amylase enzyme modifies the structure of starch so that it stays moist. Your bread may go moldy before it goes stale!

All cheese is a biotech product, and about half of the world’s cheese is made by biotech-derived enzymes. And that high-fructose corn syrup in the soda you’re drinking with the sandwich is often made with biotechnology enzyme processing.

Another example: fermentation shortens the production of vitamins C and B₂.

Fun Fact

You can thank biotech for no-calorie artificial sweeteners—**aspartame** (sold as Equal, NutraSweet), **acesulfame potassium**, **neotame**, **saccharin**, and **sucralose** (Splenda).

Other industries rely on enzymes for making fruit juice, wine, brewing, distilling, oils and fats, paper and pulp, and animal food.

Obviously, you can find biotechnology in the manufacture of many products already. Companies are well on the way to expanding the products that bring biotechnology up close and personal. For example, a new kind of polyester, using a bio-based process to manufacture 1,3-propanediol from glucose, will be better than traditional polyester in fit and comfort, softness, dyeability, resilience, and stretch recovery. The polymers used for this polyester may also be used to create new forms of plastics.

Now and tomorrow, industrial biotechnology is improving everyday products and the environmental effect they have as they are made, used, and disposed of. Next time someone asks what biotechnology has to do with your life, your answer will be a lot longer!

—Bruce Goldfarb

From-the-Hip Science

You may take a comfy pair of blue jeans for granted, but a lot of science went into making them.

The cotton from which the denim material was woven may have been genetically modified to contain the Bt gene. The gene produces a protein that kills insects, making it resistant to crop pests and reducing the need to spray with insecticides.

Cotton thread is treated with amylase enzymes to remove starch sizing, and other enzymes to enhance the intensity of dyes. The use of enzymes to process fibers and textiles is gaining favor because they are nontoxic and kinder to the environment.

The jeans are washed in cellulase enzymes, which break down the cellulose polymers of plant tissue, to produce a stonewashed look and a softer feel. Laccases provide environmentally safe bleaching of denim.

—B.G.





Humans are industrious creatures. We explore our world, we create art and music, and above all, we make things—from computers to zebra-striped backpacks, things to make us more comfortable . . . smarter . . . safer . . . and on and on.

From the Stone Age to the Age of Biotechnology, we have used our best science to improve our ability to make things. Today, it's little wonder that the science making the biggest impact on industry is biology. Cells, life's fundamental units, are experts at manufacturing all manner of complex and valuable things, which humans can use as products themselves or employ in making other things more easily, efficiently, or cheaply. Using cells and their products to manufacture things is called **industrial biotechnology**. Putting them to work on preventing or cleaning up pollution caused by people's activities is called **environmental biotechnology**.

Using cells effectively requires knowing a lot about them, including what they need to grow, how they produce the material we're interested in, and what conditions make them produce more of it.

The study of all an organism's genes is called **genomics**, and the study of all its proteins is called **proteomics**. Genomics and pro-

A Biotech Toolbox

What is industrial biotechnology, and what is the basic technology?

Career Pointer ▶ **To work in industrial biotechnology, be prepared to include more than one field of science in your studies!**

teomics produce mountains of important information about the cell. Bioinformatics uses computers for organizing and analyzing all that information. Together, genomics, proteomics, and bioinformatics provide powerful insights into how cells work and how they can be made to work for us.

Putting the Tools to Work: Cellulases

Let's see an example of how genomics, proteomics, and bioinformatics are used to solve a real problem in industrial biotechnology: finding and developing better cellulases, a type of enzyme that converts cellulose to sugar.

Cellulose is a major component of all plant cells. It is made of many sugar molecules linked in long chains. But cellulose doesn't taste sweet because we don't have an enzyme called cellulase to break the chains down into the individual sugars.

Having your own cellulase gene might not be all that useful (although it would allow you to get energy from snacking on grass or leaves!). But industry could put cellulase to work. Finding a cheap and reliable way to break down cellulose could allow agricultural wastes to be turned easily into sugars. Sugars can be turned into fuel for cars and serve as the starting material for making many chemicals that currently come from oil.

While animals don't have a cellulase gene, many types of fungi do. The biotechnology industry is already using a few types of cellulase. But current cellulases are too sensitive to changes in temperature, pH, or other conditions to be used in all the ways imagined for cellulase. Finding new cellulases, or making the current ones more robust, could open up huge opportunities in industrial biotechnology. This is where genomics, proteomics, and bioinformatics come in.

First, a researcher might start by determining the sequence of the amino acids (building blocks of proteins) that make up a particular cellulase. This is one of the major tasks in proteomics.

One way to do this is by **mass spectrometry**, which determines the mass (the property

Fun Fact

Animals that are ruminants, like cows, contain bacteria in their stomachs that provide cellulase enzyme complexes through fermentation.

that gives a body weight in a gravitational field) of molecular fragments. By chopping the protein up in different ways, and calculating the mass of each set of fragments, the

researcher can usually puzzle out the identity of each fragment and how they fit together. Bioinformatics speeds things up here. The researcher can draw on proteomic databases, which contain sequence information from many other proteins, to pick out common sequence patterns.

From the cellulase protein sequence, she can deduce something about the cellulase gene sequence. With this, she can search genomic databases that contain whole or partial genomes of fungi, looking for a match.

She might not find the exact sequence, but she may come close enough to identify genes that code for cellulases in these other organisms. One or more of these might be less sensitive to temperature or other conditions, and therefore more suitable for widespread use. The researcher can then isolate that gene, or have it built, put it into a well-known, fast-growing organism already in use (such as yeast or bacteria), and determine if this cellulase better suits her needs.

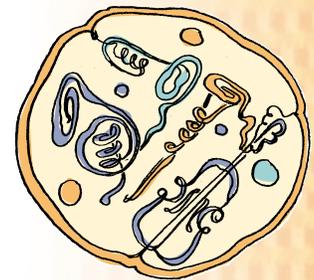
Another approach is to modify the gene for the cellulase she already has. Proteomic analysis can determine the protein's structure, which may reveal why it is so sensitive. Changing the gene sequence might improve the structure. The researcher might get clues for what to do next by looking at proteins in "extremophiles," those hardy bacteria and other creatures that live in extreme conditions. Genomic and proteomic databases of extremophiles are available for this purpose.

Many other questions will remain, including how the cell will respond to this new gene and how to stimulate it to make the most protein. Other genomic and proteomic tools help answer these questions. Newer and better tools, combined with faster and smarter ways of asking these questions and making sense of the answers, will keep genomics, proteomics, and bioinformatics at the forefront of industrial biotechnology.

—Richard Robinson

Tools for Listening to the Symphony of Life

If we think of a living, active cell as a performance by a symphony orchestra, the cell's genome is the orchestra, which contains many different instruments—the genes. Just as each instrument makes a certain sound, each gene makes a certain kind of protein. Following this analogy, genomics tries to explain what all the genes (instruments) are, when they are used to make protein (played to make sounds), what protein (sound) each makes, and how the activity of one gene affects activity of all the others in the genome (orchestra).



Proteomics tries to understand what each protein is (including its exact "note-for-note" chemical structure), how much of it is made, and how it interacts with other proteins.

Bioinformatics tries to organize and analyze this vast amount of biological data, writing down the score of music, so to speak, so others can use this knowledge for more research. —R.R.

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A Sweet Deal for the Environment

How is industrial biotech helping us decrease the use of petroleum?

Ever think about where your afternoon snack comes from? For instance, the milk and fruit in a yogurt container are produced on farms (hey, that's an easy one), but what about the plastic carton?

For the past 50 years, that question had one answer: chemicals derived from petroleum. This reliance on oil has polluted the globe and affected national policies. But today, the same corn that feeds dairy cattle is being used to manufacture soft drink cups, candy wrappers, salad bar containers, and much more.

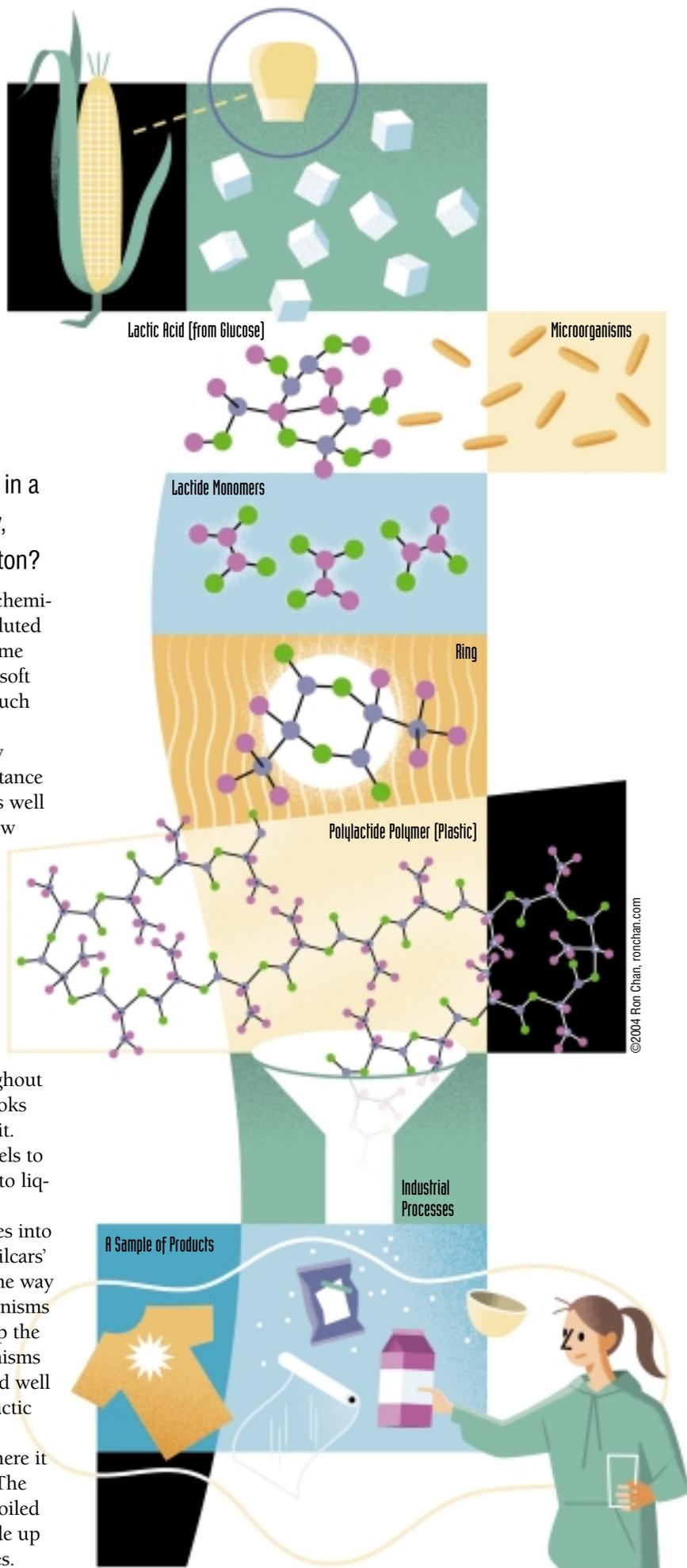
At a new Nebraska factory, field corn provides the raw material for making PLA (polylactide), a degradable substance used to make packaging peanuts that dissolve in water as well as fibers for clothing, pillows, and comforters. Cargill Dow LLC, the company that operates the Nebraska factory, calls its product NatureWorks PLA. PLA is the first commercially marketed “biomaterial,” that is, an industrial product (other than traditional foods and natural fibers) made using biological processes and raw materials from renewable biological sources, such as agricultural crops.

Bioplastic's Corny Story

Each day, the train brings bushels of corn from throughout the Midwest to a corn milling plant. The milling plant cooks the corn for 30 to 40 hours at 122° Fahrenheit to soften it. Then, machines grind and screen the softened corn kernels to produce corn starch. Enzymes convert the corn starch into liquid dextrose, a type of sugar.

Piped to a lactic acid plant next door, the dextrose goes into 10 fermentation tanks, each of which holds about five railcars' worth of corn. Fermenting liquid dextrose is similar to the way wine or beer is made. At the Nebraska factory, microorganisms break down the dextrose and produce lactic acid. To keep the fermentation process going, plant workers feed the organisms with sugar and vitamins. If the “bugs” are kept happy and well fed, they keep reproducing and make large amounts of lactic acid.

The lactic acid is piped next door to the PLA plant. There it is heated to remove water, like thickening maple syrup. The temperature is then turned up, and even more water is boiled away. The resulting product, called a pre-polymer, is made up of relatively short chains of about 10 lactic acid molecules.



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Increasing the temperature and lowering the pressure brings forth lactide, a chemical compound in the form of a ring made by clipping off two lactic acid units from the end of the pre-polymer chain. The lactide is then fed into a reactor where the lactide rings are popped open. The ends of these popped-open rings are highly reactive, and when they bump into one another, they hook up to form long chains of lactic acid units. The resulting polymer of lactic acid is known as PLA. A pelletizer forms the hot, molten PLA into little BB-size pellets that are sold to be made into various articles, such as cups, trays, films, and fibers.

The scientists and engineers of Cargill Dow were the first to figure out how to combine the fermentation and polymerization processes in an affordable way that makes the resulting bioplastic work as well (or better!) than petroleum-derived plastics. To make a PLA yogurt carton that weighs about a quarter of an ounce takes a bit more than half an ounce of corn, and more than three weeks to complete all the various steps of the plastic-making process. The PLA plant can produce 35,000 pounds of the material per hour—almost 400 metric tons in 24 hours.

Middle East vs. Midwest

Some experts predict that industrial biotechnology will be the “third wave” of biotechnology—reshaping manufacturing just as biotechnology has already transformed medicine and agriculture. One study estimates that sales of biotech-based chemicals will triple in less than a decade, rising from \$50 billion in 2003 to \$140 billion by 2010.

Three factors drive this shift:

Concern about dependence on foreign oil.

Did You Know...?

One of the earliest uses of PLA soft drink cups was at the 2002 Winter Olympics in Salt Lake City, Utah. Because PLA breaks down into carbon dioxide and water in commercial compost piles (where the temperature is monitored and maintained about 140°F, with moisture), it is ideal for food containers used for a crowd, such as at concerts or sports events. Normally food has to be separated from containers; PLA can be composted along with food scraps—saving boatloads of money. Companies, like people, are more likely to do the right thing to protect the environment if it saves them time or money!



The U.S. government sponsors research on alternatives to petroleum, including some \$75 million awarded by the Department of Energy for research and development of so-called biorefineries. Biorefineries are facilities that can produce chemicals, fuels, and electricity and heat from renewable, plant-based raw materials within a single facility, much as current refineries do using petroleum.

Environmental concerns. Most biologically based industrial processes consume less raw materials, energy, and water than equivalent chemical processes and produce little or no toxic wastes to contaminate the environment. For instance, the NatureWorks PLA process uses 20 to 50 percent less fossil fuel than techniques used to make petroleum-based plastics.

Genetic technology. Discovering the DNA sequences that code for enzymes used in industrial processes will spur the development of more effective biocatalysts.

Various companies are working to find economical biocatalysts that can break down the cellulose found in agricultural wastes, such as corn stalks, rice hulls, and sawdust, into sugars. These sugars are more difficult to process than sugars from the starchy parts of crops. Companies would like to use corn stalks and leaves rather than corn kernels to make PLA plastic.

These corn wastes can provide not only the raw material for manufacturing plastic, but also a fuel to make electricity and heat needed to run the PLA plant. Combined with some electricity from wind power, making PLA from corn wastes could save more than 90 percent of the fossil fuel needed to make plastic from petroleum!

—Karen Holmes

What Is Life-Cycle Assessment?

When companies compare how much their products affect the environment, where do these statistics come from?

One technique for scoring environmental performance is life-cycle assessment. As the name implies, these assessments consider the environmental impacts a product has at every stage of its life, from how much energy is used (and waste given off) extracting raw materials to how the product is disposed of.

The science of conducting life-cycle assessments is relatively young and highly complex. Decisions and assumptions made at each step make a big difference in the numbers assigned to products or predicted for them.

For instance, analyzing the data collected about every stage of the product's life can be tricky. If one process (for instance, milling the corn) yields several products (such as fats and fibers as well as corn starch), how much of the corn mill's total environmental impact do you attribute to each product?

Some judgments can be controversial, such as how to combine long lists of environmental impacts into a few categories and which of these categories should be given the greatest weight in evaluating a product or process.

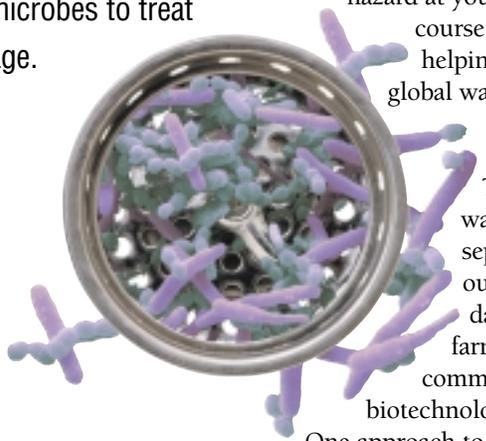
Despite these uncertainties, many companies find life-cycle assessment a valuable tool to see where their products do well and where improvements are needed. If you care about protecting the environment, one way you can make a difference is to pursue a career in one or more fields that provide the expertise needed for life-cycle assessments, such as engineering, biology, chemistry, environmental science, or economics. —K.H.

How can industrial biotechnology protect the environment?

Clean Sweep

In 1914, the city of Manchester, England, became the first city to use microbes to treat its sewage.

Today biotechnology can not only help clean up environmental messes but also keep problems from developing in the first place. It can do everything from keeping the water hazard at your local miniature golf course free of pond scum to helping the world put a stop to global warming.



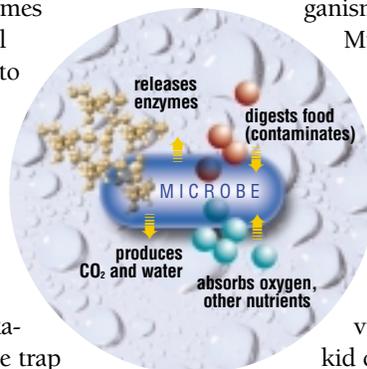
Cleaning Up Messes

The treatment of wastewater in all its forms—from septic tanks to industrial outflow to runoff from dairy, hog, and poultry farms—is one of the most common uses of environmental biotechnology.

One approach to wastewater treatment combines microorganisms with nutrients that help the microbes thrive and reproduce in harsh environments. The microbes break down the hazardous wastes, rendering them harmless in the process. A happy side effect is that the treated water typically smells a whole lot better, too.

Not all products tackle manmade pollutants. Some can help control algae growth in drinking water reservoirs, aquaculture facilities, irrigation canals, hydroelectric plants, or the local pond—anywhere that algae interferes with the water's use in industry, recreation, or landscaping. The introduced microbes outcompete the algae for nutrients in the water and produce enzymes that break down the algae's cell walls. As debris starts floating to the surface, the microbes digest it, too, resulting in clearer water.

A similar bioremediation process can take care of really nasty stuff, like oil spills. Whether it's an oil spill from a shipwreck, a leak from a gas station, or simply a clogged grease trap in a restaurant's kitchen sink, the approaches are similar.



Just as washing machines and detergent help clean our clothes,

Some cleanups use **bioaugmentation**, adding microorganisms or their enzymes to break down pollutants.

Others use **biostimulation**, providing nutrients to encourage the growth of microorganisms that are already present.

Microbes presented with a new food source—such as oil—snarf as much as possible as fast as possible, just like a kid going crazy in a candy shop. In the process, the microbes can run out of the nutrients that they need to survive and thrive. The microbes can't survive on oil alone any more than a kid can eating only candy.

Biostimulation restores those nutrients so the microbes can keep up their good work.



Microbes ©Photo Researchers, Inc., "Global Cleanup" ©George B. Diebold / CORBIS

biotechnology serves as one tool in our efforts against pollution.

Finding New Solutions

Biotechnology can clean up messes. It can also help prevent them.

Take **biomass** energy, which comes from plant remains, animal wastes, and anything else organic. Although humans have been using biomass energy since the first person lit a cooking fire, some people hope biomass will become a major source of fuel and electricity.

The most common commercial form of biomass energy today is ethanol made from the starch in corn. This isn't as environmentally friendly as it sounds, thanks to the fertilizer, pesticides, and tractor fuel that it takes to grow corn.

In the future, however, biotechnology may

make it possible to get biomass energy not just from grain but from cellulose. This "carbohydrate crude oil," as the Washington, D.C.-based Energy Future Coalition calls it, could come from stalks, husks, grass, rice straw, pulp and paper residue, turkey manure, and other agricultural waste.

The National Renewable Energy Laboratory at the U.S. Department of Energy, other government agencies, and various companies are working hard to find cheaper, more efficient ways of converting biomass into fuel and electricity—in other words, making biomass an economical alternative to petroleum. Once they achieve that goal, this renewable resource could reduce and eventually end our dependence on petroleum.

Biomass energy could also help solve the problem of global warming. That's because the amount of carbon dioxide absorbed by biomass as it's created offsets the carbon dioxide released during its combustion. Biomass energy could also reduce the size of landfills by transforming municipal wastes such as yard clippings, leaves, and tossed-out paper into **feedstock** for **biorefineries**. (See "A Sweet Deal," p. 8.) Someday someone could be paying you for your lawn clippings!

Biotechnology also has a role to play in making industry not only cleaner but also stronger. A report by the Organization for Economic Cooperation and Development called *The Application of Biotechnology to Industrial Sustainability* shows that biotechnology helps companies around the world lower their costs. Biotech products or processes can help companies reduce the amount of water and energy they use, the amount of wastewater they produce, and the amount of greenhouse gasses they emit.

Every manufacturing process involves tradeoffs, but biotechnology can play a part in cleaning up the world and helping it stay clean.

—Rebecca A. Clay

Fun Fact

Nitroreductase enzymes found in spinach and buttermilk can change explosives such as TNT into less dangerous substances.

—Pacific Northwest National Laboratory, 1998

Cleaning Up the Paper Industry

Look at a fresh sheet of paper, and you might think paper-making itself is just as clean. In reality, the pulp and paper industry is notoriously hard on the environment. Now biotechnology is helping the industry become more environment-friendly, from start to finish.

Researchers at North Carolina State University, for example, are genetically modifying aspen trees that could one day serve as a crop to be harvested instead of forests. These trees not only grow extra-fast but also contain less lignin (the glue that holds trees' fibers together) and more cellulose (the stuff the industry wants).

Other researchers are replacing electrical power with fungus power. Leave fungus, fungus food, and steamed wood chips together for two weeks, and the chips get soft and easier to grind into pulp. The result? A 30 percent drop in electricity usage.

Fungus and bacteria also play a role in reducing the industry's use of toxic chemicals. You can substitute fungus- and bacteria-derived enzymes for chlorinated chemicals used to bleach pulp. The enzymes remove part of the fiber hemi-cellulose, making it easier to remove hard-to-bleach lignin while leaving the cellulose intact. That means less chemical bleaching—and less water pollution.

—R.C.

THE ADVENTURES OF...

MR. CATALYST

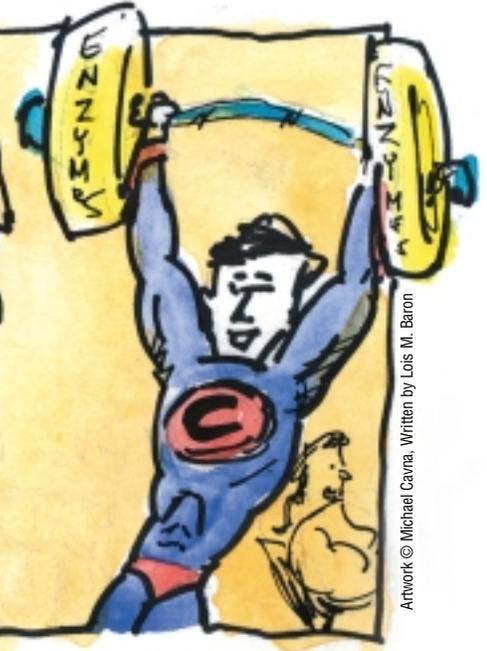
THE UNSUNG SUPERHERO!



NO PROB... ALL THE JOBS INVOLVE TRIGGERING CHANGE, SPEEDING UP THINGS...

TODAY'S ASSIGNMENT: LEATHER FACTORY, PAPER MILL, OIL SPILL, CHEMICAL PLANT, GO! GO! GO!

ALL ENZYMES ARE CATALYSTS! NOT ALL CATALYSTS ARE ENZYMES.

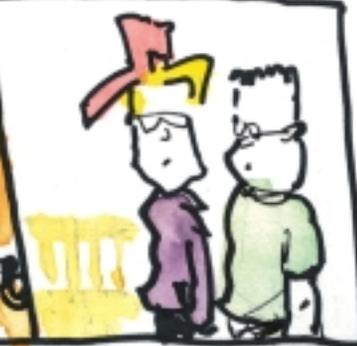


Artwork © Michael Cavina. Written by Lois M. Baron



WHAT WE MAKE ARE BIOCATALYSTS FROM BACTERIA OR FUNGI SO THEY WORK IN DIFFERENT TEMPERATURES AND PH.

THIS LITTLE GUY WILL SOLVE YOUR PROBLEM SOON.



THIS BIOFUEL CELL RUNS ON ALCOHOL AND OXYGEN. IT SHOULD REPLACE BATTERIES IN PALM PILOTS TO PAPERMAKERS!



IS THERE ANYTHING YOU GUYS DON'T HANDLE?



IT'S JUST A MATTER OF TIME!...



J. Craig Venter, Ph.D.



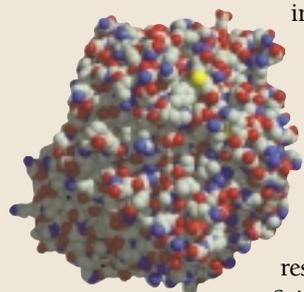
Courtesy TCGA

President and Chairman, Institute for Biological Energy Alternatives

Once you've decoded the human genome, what do you do for an encore? If you're Craig Venter, you set about saving the environment.

Venter is best-known for his work on the genetic blueprint known as the genome. As president of Celera Genomics, Venter raced government researchers to map the genes in human beings. The two groups finished simultaneously, proclaiming victory in 2000.

Venter has since spun off in several directions. He is still chairman of the Institute for Genomic Research (TIGR), which he founded in 1992. Now he heads three more organizations. The TIGR Center for the Advancement of Genomics hopes to advance science by educating policymakers, students, and others. The Institute for Biological Energy Alternatives (IBEA) conducts environmental research. And the J. Craig Venter Science Foundation provides support to the three groups.



Carbon Dioxide

Venter's work at IBEA is perhaps most urgent. "After I finished sequencing the human genome," he said, "I considered the

most important societal issues and decided that environmental problems were the most pressing ones for our survival."

The institute is taking a multi-pronged approach. One goal is to use genomics to assess entire ecosystems and monitor changes invisible to the naked eye. An avid sailor, Venter launched this new field of environmental genomics with a look at the Sargasso Sea. Relying on the once-controversial "shot-gun" technique he used for the human genome, the effort used high-powered computers to reassemble random bits of sequenced DNA.

The result? The discovery of at least 1,800 new microbes and a million-plus genes—astounding biodiversity in an area once thought relatively lifeless. "If you use DNA sequencing to look closely at seawater, you can make more discoveries than all marine biologists have made in the last decade," said Venter. "In a cup of seawater!"

Another goal is to find ways to keep carbon dioxide (CO₂) out of the atmosphere and prevent global warming. Our society relies so heavily on burning oil and coal, Venter explained, that we've exceeded the capacity of micro-organisms and plants to use the resulting CO₂. "We're seeing if we can use genomic tools to speed up organisms' metabolism to capture the CO₂ at a rate that would help undo the damage we're doing," he said.

Developing an eco-friendly fuel source, such as hydrogen, is yet another goal. Although hydrogen-production techniques already exist, they're expensive. And in the US, hydrogen is extracted from oil—a process that itself produces CO₂. Venter hopes instead to harness biological power to produce hydrogen or other clean fuels. "Many organisms produce hydrogen and methane but not the large amounts required to run automobiles or airplanes," he explained. IBEA has already created an artificial virus, a success that brings them closer to creating a customized, hydrogen-producing microbe.

Venter's early teachers probably never suspected their student would become a world-class scientist. Back then, Venter was more committed to surfing and girlfriends than studying. It wasn't until he returned from a stint as a medical corpsman in Vietnam that he got serious. Intent on medical school, he got hooked instead on basic science and went on to earn a doctorate in physiology and pharmacology from the University of California at San Diego.

Said Venter, "My career should give hope to lots of parents!"

—Rebecca A. Clay

Make Your Own 'Green' Plastic

One of the most fun, as well as eye-opening and informative, ways of learning about green plastics is to **MAKE THEM YOURSELF!** Yes, you can make biodegradable plastic in your own home, cheaply and easily, using materials found in the home or in schools. Here's how to make a transparent glass-like sheet that can be used in small picture frames as a substitute for glass or Plexiglas.

Safety Tips

- Be careful around open flames if using a gas stove
- Remember hot plates stay hot long after they have been turned off
- Use ovenproof mitts to handle hot substances
- Keep all substances away from skin and eyes
- Wear goggles
- Wash hands before and after the activity.



In a heat-proof container, add 12.0 g (4 teaspoons) unflavored gelatin to 240 mL (1 cup) of a 1 percent glycerol solution (a 1 percent glycerol solution has 10 mL of glycerol for every liter of water, or 2 teaspoons of glycerol for every quart). Glycerol, also called glycerin, is often available in drugstores.

What happens if I add more water? more gelatin?
What happens if food coloring is added?



Keep stirring until there is no further dispersion of the components.

What happens if I stir it for 1 minute versus 2? 3?
Does it have to be stirred?



Using a hot plate or microwave,* heat the mixture to 95°C or to the first point of frothing, whichever comes first. Stir again. There should be no visible lumps. *If using a microwave, use a container that is twice as large as the volume of liquid.

What happens if it is heated to 10°C? 20°C?
Is there a difference between heating with a microwave and a hot plate?



Carefully empty the mixture into a nonstick brownie pan, approximately 25 cm x 15 cm (10 inches by 6 inches). If needed, you can spread out the mixture to cover the bottom of the pan.

What if it is poured on a warm surface? cool? cold?



Let the pan sit undisturbed for as long as it takes for the mixture to dry, which may be several days, depending on room temperature and humidity.

Does a hair dryer affect how the plastic forms?
a drying oven?

You can make a more flexible sheet by increasing the relative amount of the plasticizer glycerol. There are many other formulations in the book *Green Plastics*, as well as suggestions for measuring some of the physical properties of the sheets-like tensile strength and their biodegradability.

Stevens, E. S.: *Green Plastics*.
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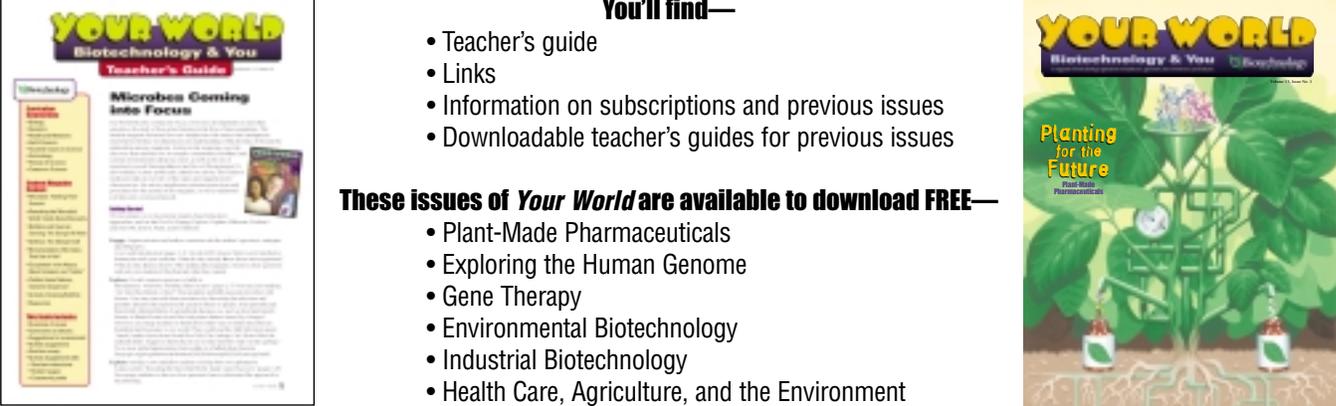
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Glossary

Biomass: Total mass of living material in a given area. Plant and animal waste used as fuel.

Biocatalysts: In bioprocessing, an enzyme that activates or speeds up a biochemical reaction.

Extremophile: Microorganisms that live optimally at relatively extreme levels of acidity, salinity, temperature or pressures; discovered through bioprospecting.

Genetically Engineered Enzymes: Enzymes derived from genetically modified organisms (GMOs). GMOs are obtained by changing the genetic material of cells or organisms so they can make new substances or perform new functions.

Renewable: Resources able to be sustained or renewed indefinitely, either because of inexhaustible supplies or because of new growth.

Sustainability: A goal that aims toward preserving quality interactions with the local environment, economy, and social system.

Resources

Online Resources for Teacher's Guide

- Biobased Industrial Products: Research and Commercialization Priorities*
National Academies Press (2000); <www.nap.edu/catalog/5295.html>
- "Biomass Research," <www.nrel.gov/biomass/biorefinery.html>
- "Biotechnology in the Leather Industry," U.K. Department of Trade and Industry, BIO-WISE, and BLC Leather Technology Centre
<www.biowise.org.uk/docs/2000/publications/leather.pdf>
- "Enzyme Technology," Martin Chaplin <www.lsbu.ac.uk/biology/enztech/index.html>
- "Ethanol: Separating Fact from Fiction," U.S. Department of Energy
<www.ott.doe.gov/biofuels/pdfs/factfict.pdf>
- Mining & Minerals FAQ, Natural Resources Canada (2002)
<www.nrcan.gc.ca/biotechnology/english/m_faq7.html>
- "Nanotechnology," Biotechnology and Biological Sciences Research Council
<www.nanotec.org.uk/evidence/81aBBSRC.htm>
- BIO <www.bio.org> (click on "Industrial & Environmental")
- BIOWISE <www.biowise.org>
- EuropaBio <www.europabio.org/pages/index.asp>
- National Renewable Energy Laboratory <www.nrel.gov>

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The Biotechnology Institute awards thousands in CASH prizes to students (Grades 9 to 12) for biotechnology science research projects through the Aventis International BioGENEius Challenge. This year, winners of the Northeast and Southwest regional challenges will meet to compete in San Francisco June 5 to 7.

Prepare now for the 2005 BioGENEius Challenge in Philadelphia. Contact your state coordinator by visiting <www.biotechinstitute.org/biogene.html>.



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