Biop
Fantast

MY DESK IS LITTERED WITH ORDINARY-SEEMING ITEMS. There's a silky white T-shirt, a square of rugged carpeting dyed beige, a long paper sleeve with a cellophane-like window for packaging a loaf of French bread, and one of those transparent, hinged pods familiar to salad-shoveling office workers who buy lunch at health-food emporiums. These items have something startling in common: The plastic in the salad pod, the fibers in the T-shirt and carpet square, and the clear stuff in the bread sleeve's window are all bioplastics, materials based not on petroleum but on corn. Just a few months ago the stuff they're made of was brewing in the guts of corn-sugar-munching bacteria in huge vats at a plant in Nebraska.

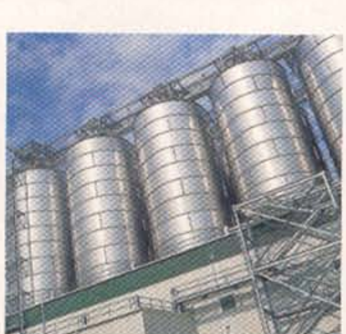
This humble collection of workaday items heralds a transformation that could reshape the industrial world and reduce our dependence on oil, the primary feedstock for almost all of the mountains of plastic we consume. Like the drugmakers before them, chemical companies large and small are awakening to the power of genetically engineered organisms to produce essential materials. "We want bugs that are engineered so that their whole purpose in life is to eat sugar and poop out plastic, staying alive just long

Making plastic without oil

Biotech's next chapter: Chemical makers are replacing petrochemistry with life science.

Corn
The lowest-cost source of sugar in North America, corn is the starting material for bioplastics.

Corn syrup
Machinery extracts dextrose from the corn and suspends it in a water solution.



Vats of bacteria
The syrup gets fed to microbes in huge fermentation vessels.

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Bugs that eat sugar and poop polymers could transform industry—and cut oil use too. by Stuart F. Brown

enough to do this. And now we've got them," exults a DuPont executive. Done right, the biotech processes are showing that they can compete with petrochemicals on cost, and some of their products are even biodegradable—a feature that lends the nascent bioplastics field a powerful green allure.

The most visible symbol of this sea change in manufacturing technology is a new Cargill Dow plant that towers above the flat corn country in Blair, Neb. The joint-venture company is producing a plastic called polylactic acid, or PLA, which competes with traditional petroplastics like polyester and PET for use in packaging and clothes. Besides the stuff on my desk, fibers and films from Cargill Dow's PLA are finding early markets around the world in pillows, food and candy wrappers, and more.

Chemical giants like DuPont, as well as small, research-oriented startups like the MIT spinout Metabolix in Cambridge, Mass., are beavering away on plastics brewed up in fermenters full of living organisms and nutrient broth. While biotech chemicals account for just a smidgen of total sales today, it's a trend that could quickly add up to a very big deal, according to a recent McKinsey & Co. study. McKinsey principal Rolf Bachmann estimates that by 2010, chemical products made at least partly by biotech methods could account for $280 billion of a projected $1.4-trillion-a-year chemical market. Sales that large would displace a notable quantity of oil, freeing it up for other uses and helping keep prices down—

Plasticky gobs
Microbes convert the sugar into plastic precursors or plastic itself (the white blobs above).

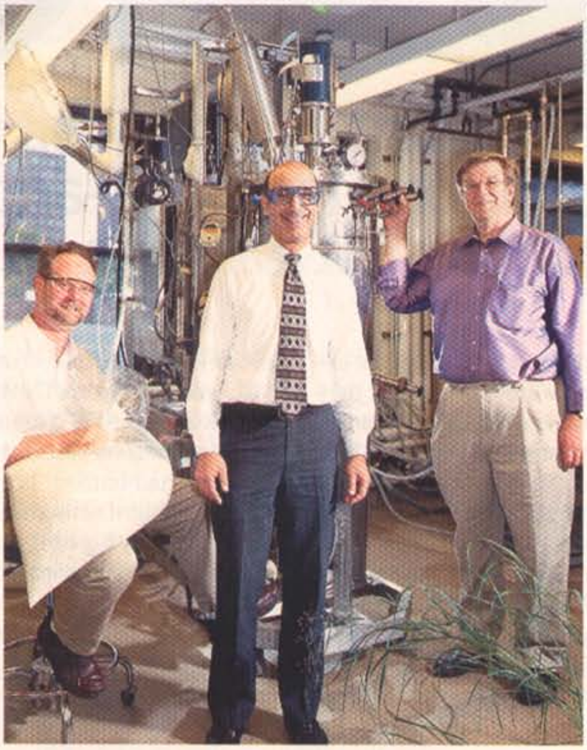
Plastic pellets
After purification, the plastic gets molded into pellets for shipment to customers.

Cups, clothes ...
Manufacturers turn the pellets into everything from containers to T-shirts.

though no one can yet estimate by how much. It would also shift the source of industrial chemicals from foreign countries to farm fields nearer the markets where the end products will be consumed. That would cut transportation costs and conceivably reduce dependence on foreign oil.

Much of today's bioplastic manufacturing is really about corn. Cargill Dow's program has its roots in the late 1980s, when one of the partner firms, grain processor Cargill Inc., decided to fund R&D for new corn markets. By the mid-1990s its scientists had shown that bacteria known as *lacto bacilli* (which also live in yogurt) can be harnessed to produce lactic acid—a plastic precursor—more cheaply from corn sugar than by traditional chemical synthesis methods. (Actually the bugs would be just as happy eating cane sugar, say, or sugar derived from any abundant "biomass.") Cargill formed its joint venture with Dow Chemical Co. in 1997, and the venture broke ground for the Nebraska plant in 2000. Within three years the plant was cooking up lactic acid in 300,000-gallon stainless-steel fermenters, "polymerizing" it into PLA, and shipping the bioplastic in pellet form to customers.

Bioplastics is still in its early days, so Cargill Dow's production costs are higher than those of its petroplastics competitors. Says chief technology officer Patrick Gruber: "There's a lot of potential for future cost reductions." Yet the cost hasn't stopped early adopters, like the Boulder organic-market chain Wild Oats Markets, which uses Cargill Dow's salad trays. The PLA trays, which sell with the brand name NatureWorks molded into the bottoms, are rated "compostable"—they will break down when disposed of in a properly managed landfill. Ecologically minded Wild Oats customers are willing to pay a little more for that attribute.



GREG BETZ

Green manufacturing

Metabolix's Oliver Peoples (left), James Barber (center), and Tony Sinsky have convinced jumped up *E. coli* bacteria to become mini-plastics factories.

The love affair with corn extends beyond Cargill Dow. At DuPont, the nation's second-largest chemical company and a major consumer of oil, CEO Chad Holliday attracted a lot of attention several years ago by declaring that the company would aim to obtain 25% of its revenues from nondepletable resources by 2010. DuPont's formidable experimental station at its headquarters in Wilmington, Del., has long been at work on the mysteries of making biotech chemicals. Now it looks as if DuPont's first polymer made by life science instead of traditional synthetic chemistry will be a corn-based fiber called Sorona.

Soft, springy stuff that competes with polyesters, Sorona is making its first appearance in women's activewear, where its ability to take bright, splashy dyes and resist the ravages of chlorine make it a natural choice for swimsuits. The fiber—which wears the chemical name 1,3 propanediol, or PDO—can be either brewed in a biotech vat or cooked up by more expensive synthetic-chemistry means. As scientists were perfecting the Sorona bioprocess in the labs, DuPont primed the textile market with chemically synthesized batches. Although the company hasn't yet committed to building a bioprocessing plant for the stuff, DuPont execs say the financial case for Sorona is strong, and a launch decision could come soon.

The case for Sorona is strong because the scientists have produced a Sorona-making superbug. Working in collaboration with metabolic engineering experts at Genencor International of Palo Alto, the DuPont team started in the early 1990s with a culture of genetically modified *E. coli* that produced tiny quantities of PDO. To achieve commercial-grade output, says senior research associate Charles Nakumura, "we had to essentially invent the organism." Normal *E. coli* devotes a whopping 67% of the sugar it consumes to obeying its natural programming, which simply says: Make more of me. Years of hard work reduced that percentage in the Sorona bugs to just 17%. The remaining 83% of the sugar's energy goes into PDO.

Bacteria with a fierce work ethic can also be found at Metabolix, a biotech firm founded in 1992 atop patents licensed from nearby MIT. A few years ago Metabolix succeeded in developing a variety of jumped-up *E. coli* that can produce not just plastic precursor materials, or monomers, but the polymers themselves. Part of the trick is inserting several genes into the *E. coli*'s DNA that cause it to generate enzymes, or biocatalysts, within the cell. The enzymes first produce raw materials and then join them to form the plastic. The family of biodegradable materials made this way are called polyhydroxyalkanoates, or PHAs, and can be produced with mechanical properties varying from stiff to rubbery.

Chief scientific officer Oliver Peoples has a photomicrograph of one of his PHA-making microbes that's just astounding. The little bug's innards are utterly dominated by huge gobs of the polymer it's internally manufacturing. There's far more plastic than bug body inside one of these little devils, about 85% of its dry weight. For the past few years Metabolix has concentrated on scaling up its process from the lab, where a benchtop fermenter may contain just 20 liters of nutrient broth, to commercial-scale 60,000-liter batches. The U.S. military could be the first customer—the Pentagon is testing biodegradable PHA forks and spoons to pack with MREs, those "meals, ready-to-eat" that fuel troops in the field.

Even as the researchers are driving down the cost of bioplastics, they are grappling with another major challenge: The new materials won't get serious consideration unless they can be used with the molding and spinning and weaving machines that already populate the factories of prospective customers. But the fact that giant companies are making earnest investments shows that the idea of sustainability—of shifting from oil to raw materials that can be grown anew each year—could blossom into a very big thing. ■

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CORN, BEAKER, AND PLASTIC CUPS AND CONTAINERS: NICHOLAS EVELEIGH; BACTERIA: METABOLIX; CARGILL DOW; FACTORY AND PLASTIC PELLETS: CHRIS VOLK