



PEGGY GREB (D309-1)

Chemist Victoria Finkenstadt displays different samples of electroactive bioplastics developed in her laboratory at the National Center for Agricultural Utilization Research.

Electroactive Bioplastics Flex Their Industrial Muscle

Today's robots are nimbler than ever thanks to artificial muscles made of conductive polymers, a breed of shape-shifting plastic that bends, bulges, and contracts when stimulated by electricity or when charged particles called "ions" are used.

Efforts are also under way to put these same polymers to work in biomedical applications, specialized sensors, light-emitting diodes, and even the next generation of robotic Mars rovers.

The material's space-age promise could get a further lift from efforts of ARS scientists in Peoria, Illinois. Most conductive polymers in the developmental pipeline are petroleum based. But Vicki Finkenstadt and J.L. Willett have shown that plant polysaccharides, such as starch and cellulose, work just as well.

In these interlinking chains of glucose the researchers see an affordable, home-grown resource that sidesteps some of the pitfalls associated with petroleum feedstocks. Chief among these is U.S. reliance on foreign suppliers and—more generally—pollution tied to the manufacture, use, and disposal of petroleum's derivative products.

"Starch, cellulose, and chitin are some of the most abundant natural polymers on Earth . . . [and] have a wide range of uses, functioning as energy storage, transport, signaling, and structural components," write Finkenstadt, a chemist, and Willett, a supervisory chemical engineer, in the February 2005 issue of *Applied Microbiology and Biotechnology*. Both work in the ARS National Center for Agricultural Utilization Research in Peoria, where 100 full-time scientists pursue new, value-added uses for midwestern crops.

"Our electroactive bioplastics offer new market options for agricultural products and illustrate their potential for advanced uses," says Willett, who leads the center's Plant Polymer Research Unit. "Their renewability and relative ease of processing reduce environmental impact."

Finkenstadt notes that one characteristic of synthetic polymers is their disorganized molecular structure, which can slow the free flow of electrons. Because of this, she says, "Synthetic conductive materials have had a limited range of conductivity, were difficult to cast into shapes, and became brittle after a few cycles of use."

Polysaccharides, by contrast, have a predictable and uniform molecular structure, making them relatively easier to shape and process on a large scale.

“Our electroactive bioplastics can be molded or made into a film or powder,” says Finkenstadt, “and the material is environmentally friendly and inexpensive.”

Indeed, cornstarch—the researchers’ polysaccharide of choice for making the electroactive bioplastics—currently sells for less than 20 cents a pound. By comparison, a gram of a polyaniline emeraldine-based polymer costs \$58. (Note: 454 grams equal 1 pound.)

Polysaccharides are also plentiful, especially cornstarch. In 2004, U.S. farmers planted nearly 81 million acres of corn and harvested close to 12 billion bushels. About 280 million bushels of that total was processed for starch. But the researchers say the electroactive bioplastics can be made from other polysaccharide sources, too. “We’re interested in any polysaccharides, even those from bacterial sludge and seaweed,” says Finkenstadt.

Many polysaccharides are natural insulators. But their electrical conductivity must be teased out by science. Otherwise, they’re unlikely to compete with petroleum feedstocks in the nearly \$1 billion U.S. conductive-polymers market.

In nature, starch is a granular crystal comprising two kinds of polysaccharide, a linear form called “amylose” and a branched form called “amylopectin.” For starch to perform the tasks expected of today’s polymers—like flexing the artificial muscle of a robotic arm—the crystal must first be broken down by heat or mechanical force.

This is done by a process called “reactive extrusion.” Says Finkenstadt, “The starch is gelatinized with heat and moisture, plasticized with water, and doped—all in one continuous process.” (“Doping” is a procedure whereby various salts called “halides” are dissolved into the solution to improve ionic conductivity.) “Reactive extrusion makes it feasible to use existing equipment for scale-up to an industrial level,” she adds. “It’s also less labor-intensive and more time-efficient.”

Finkenstadt and Willett’s tests so far indicate conductivity levels on par with those of existing synthetic conductive polymers. Their goal is to match that of

polyaniline emeraldine-based polymers, among the most widely used types.

“Our material uses ionic conduction, much like the nerves and muscles in your body,” Finkenstadt explains. “The material is inert until an electrical charge is applied,” at which point it expands or bends, contracting only when the current stops.

The researchers hope their bioplastics’ expected compatibility with the human body will lead to various medical applications, including controlled-release devices like insulin pumps and nicotine patches.

In tests, the bioplastics demonstrated “reversibility of the electrical charge”—the flow of ions back and forth across the material as electrical charge starts and stops. Finkenstadt says the property could benefit lithium batteries. Petroleum-based gels are now used for some of these to facilitate recharging. But Finkenstadt plans to study whether replacing them with the electroactive bioplastic will allow faster recharge or longer charge storage.

Rust prevention is another potential use the ARS researchers are investigating along with a commercial partner. According to Finkenstadt, a 3-inch-thick coating of grease is applied to virgin steel components, such as beams and sheets, to preempt rust formation during transport to assembly plants. Cleaning and disposal of the grease is a major problem and expense. Finkenstadt says the same rust protection may be achieved by spraying a micrometers-thick film of electroactive bioplastic, which can later be cleaned off with environmentally friendly enzymes.

The patentability of these and other applications is now being reviewed. Says Finkenstadt, “I anticipate we will have some working prototypes in the coming months.” —By **Jan Suszkiw**, ARS.

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Technician Richard Haig evaluates the strength and flexibility of starch-based electroactive bioplastics.

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Research leader J.L. Willett (right) examines extruded electroactive bioplastic film designed by Victoria Finkenstadt.