PRINCETON PLASMA PHYSICS LABORATORY
fact sheet

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U.S. DEPARTMENT OF ENERGY

A Stimulating Experiment:

Scientist's Quest For Artificial Muscle Aided by PPPL

Lenore Rasmussen was a laboratory technician in Virginia in 1986 when she had a Dr. Frankenstein moment.

She was shooting electrical current through a slab of polymer gel when, suddenly, the blob seemed to come alive. Hit with 50 volts of current, the gel convulsed, shrinking to a fifth of its size. When she stopped the current, the gel returned to normal. It hadn't done that before.

"That was weird," she remembers thinking. Still an undergraduate at Virginia Polytechnic Institute, she couldn't then fully investigate what had happened. If a gel could contract and recover, she wondered, why couldn't it be used as artificial muscle? "I filed it away up here," she said, tapping her forehead.

Now an independent chemist working with scientists at the U.S. Department of Energy's Princeton Plasma Physics Laboratory, Rasmussen is working on an electroactive gel that may soon be used for artificial muscle, prosthetic devices, catheters, valves, and a number of other applications. By tying in her electroactive materials with fuel cell technology, she is not only developing a novel way to perform life-like movement, but is also providing for an energy efficient method to provide work and movement.

By dint of hard work, she has emerged as a leading expert in her chosen field of electroactive polymers. She is the editor of Electroactivity in Polymeric Material, a book to be published next year by Springer-VDI-Verlag GmbH & Co. KG. Her chapter details the theory of contraction.

What's more, the opportunity to use the laboratory's facilities and its scientists' expertise, she said, has allowed her to achieve a breakthrough in resolving a technical issue related to electrifying the gel. With that hurdle cleared, her earlier laboratory mishap—she had mixed the gel wrong—has led to promising work on this new "smart" material.

Rasmussen's quest to harness the gel's peculiar traits is now her fulltime pursuit, an effort officially known as the Artificial Muscle Project. "There are significant challenges ahead, but it is possible. I'm confident about that and about the field in general," said Rasmussen, who heads her own Princeton-based start-up called Ras Labs.

Lenore Rasmussen, founder of the start-up Ras Labs, has achieved a breakthrough in her understanding of how to control the behavior of an electroactive gel. Her work, much of it conducted in partnership with the U.S. Department of Energy's Princeton Plasma Physics Laboratory, could lead to the creation of artificial muscles, to be used in prosthetic devices, catheters, valves and a number of other medical applications.

Under an arrangement known as a Cooperative Research and Development Agreement (CRADA), Rasmussen has been working since 2007 with Lewis Meixler, head of applications research and technology transfer at PPPL, to put the gel's unusual traits to work.

An independent chemist now working at PPPL, Lenore Rasmussen says the Laboratory has given her the ability to make advances by allowing her access to its scientists' expertise and unique facilities.

Meixler helped open the laboratory's doors to Rasmussen after they met in 2005 at a state-sponsored conference for small business entrepreneurs in science and technology. Under the CRADA, Rasmussen pays many research costs, such as that of materials and the overhead at her Ras Labs. She also contributes work-in-kind to the laboratory and its staff. In return, she gets use of PPPL's facilities.

The partnership is winning accolades from experts in entrepreneurial pursuits.

"From my point of view, what Lew and Lenore are working on is cutting edge and visionary," said Tom Brown, the Department of Energy's Federal Laboratory Consortium Northeast Regional Program Manager. The CRADA agreement is making the research possible, he added. "It's a side benefit of our tax dollars at work," Brown said. "The little guy gets to work with technology and facilities he would not have access to otherwise."

That's particularly true when it comes to finding funding for basic research, Meixler noted.

After years of research, Rasmussen better understands why the gel contracts. It has to do with a negative electrode attracting sodium ions, which then stream out of the gel, dragging water with them. That causes the substance to shrink like a squeezed sponge. Once the current is off, the party's over and the sodium ions go back to the gel, which then quickly resumes its size. "Most polymers are hydrophobic, shunning water," she said. "Mine is hydrophilic. It's a water-loving material."

Coming up with the best formulas to make such substances is only the first step. Next is finding a way to securely embed electrodes in the gel and to control and refine the contractions. That includes being able to use a small plasma generator. It was this piece of equipment that led to her research breakthrough. She is using it to treat metal electrodes so that the gel and electrodes in it will remain attached. Previously they tended to separate after repeated use.

Recently, in a lab session, as Rasmussen watched a titanium wire glow in the generator's purple plasma, she said she is well aware treating metal with plasma--super-heated electrically charged gases--is not something she could easily do elsewhere. "I could never afford this in a million years," Rasmussen said.

Developing artificial muscle has been her top priority for years. "I'm obsessed with it," she said. Coming up with such a material has been on her mind ever since a cousin had a devastating farm-machinery accident that nearly cost him a leg.

Fearing the injured man needed an amputation, the family gave Rasmussen the task of deciding which prosthetic would be the best. She scoured medical catalogues, contacted

Rasmussen frequently works with students to involve them in her research. From left, high school interns Aparna Panja and Victoria Jones assemble materials for an experiment.

suppliers, and visited prosthetic companies, but "I just didn't like anything I saw out there," she said.

She is optimistic that her work will yield improved prosthetics that would more closely simulate the natural muscle movement of human limbs. Rasmussen also sees many other possibilities for using a material that can quickly contract and expand. Such a contracting substance could behave like the muscle tissue in the human gut. Shaped into a series of rings it might squeeze water through a tube. That option could also be put to use in inventing a water pump for irrigation in remote areas.

The gel could, in addition, be used in making a more energy-efficient motion by incorporating a fuel cell, where the hydrogen given off by a side reaction is converted into electricity.

The substance also could be used in robotic devices, particularly where fine manipulation control is needed. Or, it could be designed to power many kinds of valves, including ones used to repair damaged hearts.

Medical device manufacturers could use the gel, Rasmussen said, to make catheters that would change size, shrinking so they could be easily inserted, then swelling to the appropriate size after they were in place. That would make catheter insertion more comfortable for patients and easier for caregivers.

Creating arterial stents that shift size is another possibility. Improved Braille reader is another potential application. A page in a book could be programmed to change its configurations of raised Braille markings just as other ebooks control pixel displays.

The DOE is encouraging its labs to develop such partnerships to help scientists, Brown said. At the same time, under DOE policy, PPPL is focused on supporting ventures owned by the disadvantaged, minorities, and by women.

As a woman-owned small business, Ras Labs meets some of those standards. PPPL managers, nonetheless, are very selective in entering into such CRADA arrangements, Meixler said. Setting the bar high has paid off in some notable successes, Meixler added. Those include a sensitive detection system now used to identify any potential radiological threats from a "dirty bomb." The system, called the Miniature Integrated Nuclear Detection System, and known by its acronym MINDS, was developed at the laboratory under a CRADA arrangement. It has since been deployed at McGuire Air Force Base in New Jersey, container shipping ports in Long Beach, Cal., and Singapore, and is being tested for use in railway and bus stations by the New Jersey Transit system. MINDS can distinguish "threat" radiation from that emitted by natural, medical, or industrial sources. MINDS can detect one-billionth of such a material within two seconds.

Several Princeton facilities are involved in Rasmussen's research. They include the Princeton Environmental, Analytical Radiological Laboratory (PEARL) at PPPL and the Princeton University Department of Chemistry and other facilities on the main campus, including the University's Image and Analysis Center, part of the Princeton Center for Complex Materials.

Lewis Meixler, at left, head of applications research and technology transfer at PPPL, has been working with Rasmussen since 2007 under a federal Cooperative Research and Development Agreement. Rasmussen pays many research costs. She also contributes work-in-kind to the Laboratory and its staff. In return she gets use of Laboratory facilities. At center, Alice Kirk, a high school teacher, and Sarah Newbury, a high school intern, discuss materials research.

Learning that she could have access to the talent and equipment at PPPL was a turning point for Rasmussen, a pivotal step in a long journey.

She grew up in farm country in West Virginia. She thought she wanted to be a large-animal veterinarian. She took science classes and fell in love with chemistry. "It's very Wizard-of-Oz," Rasmussen said.

In the years since her initial lab observation about the electro-responsive gel at Virginia Tech, Rasmussen went on to get a master's degree in biology at Purdue University, and returned to Virginia Tech for her doctoral degree in polymer chemistry.

She later took a position at a major New Jersey medical research company.

The terror attacks of September 11, she said, forced her to reflect on her own career and life goals. "I did some soul-searching," she said. Leaving her secure position, Rasmussen decided to strike out on her own to focus solely on socially relevant topics. She rented lab space from a complex on Route One, and in 2003 founded Ras Labs, a one-woman operation. Then, relying mostly on teaching, income from consulting and patent searches, she went back to work on her own projects, notably the mysterious behavior of that electroactive gel.

"I decided to see if my crazy idea worked." She's never looked back. ■

The Princeton Plasma Physics Laboratory is operated by Princeton University under contract to the U.S. Department of Energy. For additional information, please contact: Office of Communications, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08543; Tel. (609) 243-2750; e-mail: **pppl_info@pppl.gov** or visit our web site at: **www.pppl.gov**.