Researcher creates bioinspired and biofunctional materials for widely diverse applications

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Brad Olsen Credit: David Sella

In one project, Brad Olsen's lab seeks to engineer soaps that can be sprayed onto a toxic chemical release and not only wash off the chemical, but detoxify it. In another, he is joining with numerous collaborators to lay the foundations for "sustainable biorefineries" that can turn solid waste or algae into a renewable feedstock for a wealth of new materials. A third effort aims to develop new kinds of injectable hydrogels that can stabilize a deep wound, or carry treatments into diseased tissues.

These are just a few of the Olsen lab's investigations, driven by new materials that are derived from, or inspired by, biology. "We focus on engineering new materials out of proteins, protein-polymer hybrids, and different types of polymers, with a particular focus on materials that can be processed in water," says Olsen, an assistant professor of chemical engineering at MIT. "We apply these materials to a variety of applications, from biomaterials to new sustainable polymers to technologies that address concerns in national defense and in energy."

The new materials "can act as interesting models for testing fundamental scientific questions," Olsen adds. "For example, we can build polymers with new shapes, or new sequences of monomers that endow them with specific properties. We try to understand how construction of these molecules leads to changes in the mechanics of the material, or the way in which material self-assembles, or aspects of how the material might undergo certain dynamic processes. And then by understanding these fundamental scientific questions, we can move the capabilities of the materials forward to address many different applications."

Defending against toxic threats

In several programs for MIT's Institute for Soldier Nanotechnologies, Olsen and colleagues are addressing chemical and biological threats with innovative biological materials, which potentially offer "a selectivity for compounds within diverse environments that is hard to get with other types of technologies," he says.

One initiative, in which his lab collaborates with the Army's Natick Soldier Research, Development and Engineering Center (NSRDEC), is developing soaps that can decontaminate large areas in an environmentally friendly manner.

"Many toxic chemicals are hydrophobic, so they don't easily dissolve in water," Olsen explains. "One needs to use some kind of soap to get the chemical off the surface and into water. One would also like to be able to degrade this chemical, rather than having to recover the water, which can be very difficult if you're trying to wash large areas or complex structures, and treat it as a toxic waste."

Olsen's lab and NSRDEC are pursuing a solution in which soap forms a "nanoreactor" whose outside is coated with enzymes that can actively degrade the toxic chemical. "In an ideal situation, the chemical becomes a harmless solution that won't have to be recovered for wastewater treatment," he says. "The great thing is that if you use both soaps and enzymes that are environmentally friendly, potentially you won't have a toxic soap formulation either."

With working prototypes in the lab, the researchers are now tuning the nanoreactor chemistry to be faster and more stable, and testing how well the approach functions against a broader set of toxins.

Two other security projects look at producing new protective barrier membranes that respond only to dangerous threats in the environment.

One effort "is to make smart membranes that will protect you when you are in the presence of a toxic chemical, but be breathable and easy to wear in the absence of a toxic chemical," he says. This effort is a partnership with researchers at MIT, NSRDEC, and the University of

California at Santa Barbara.

A second study, with Katharina Ribbeck, the Eugene Bell Career Development Assistant Professor of Tissue Engineering in the MIT Department of Biological Engineering, aims to understand the biology of certain biological barriers, and to find ways to copy them to keep people free of pathogens.

Building a sustainable biorefinery

Another major theme in Olsen's research is tapping biological feedstocks to supplement petroleum feedstocks for the next generation of chemical processes. "As these new processes and products start to be identified, the chemical industry will see important near-term impact," he predicts.

Olsen has joined in a major collaboration with Professor George Stephanopoulos, Associate Professor Kristala Prather, and Assistant Professor Yuriy Román of MIT's chemical engineering department, along with researchers at the Masdar Institute in Abu Dhabi. The project will examine the use of biomass from Abu Dhabi municipal and agricultural waste and algae to explore chemical and biochemical pathways and processes that can help in producing biofuels and other advanced biomaterials.

"We're hearing from many companies about the strong interest in exploring this wider variety of feedstocks in chemical processing," Olsen says. "What really excites my group is looking at how these biological feedstocks can help us develop the next generation of materials, with more favorable lifecycle analysis, or less use of toxic monomers, or better combinations of properties than those of existing materials."

Healing wounds with hydrogels

On the medical front, one leading project is to engineer different kinds of hydrogels with mechanical properties that haven't previously been achievable in a biomaterial system, Olsen says.

"Hydrogels are traditionally quite brittle and quite fragile," he points out. "If you want a hydrogel to be more like human tissue, there's a long way to go between Jell-O and human tissue. So we work on targeting some of those technology gaps."

In an Institute for Solider Nanotechnologies collaboration with Ali Khademhosseini of the Harvard-MIT Division of Health Sciences and Technology and Professor Gareth McKinley from MIT's Department of Mechanical Engineering, Olsen's team focuses on injectable hydrogels that are designed to stop bleeding in battlefield wounds. Their goal is to create a nanostructured protein hydrogel for an implant that can not only stop the flow of blood but aid in subsequent healing, and then be absorbed by the body.

Existing "shear-thinning" hydrogels have the ability to switch from solidlike to liquidlike states when under mechanical stress, Olsen notes. When injected in the body, they can switch from liquidlike form in the syringe into solidlike form for the implant. However, the hydrogels then must durably maintain that form despite any mechanical stresses they encounter.

Olsen and his colleagues are developing a hydrogel that reinforces a network of proteins with polymers that are soluble in water at lower temperatures but are insoluble when heated to body temperature, so that they form a grid that makes the hydrogel much stiffer and slower to degrade. Additionally, the proteins in the hydrogel are chosen partly for their role in promoting wound healing.

Seeking sustainability

Other work in the Olsen lab, funded by the Department of Energy, the Air Force Office of Scientific Research, and the National Science Foundation, focuses on advances in sustainability, with an emphasis on biocatalysis.

"We're looking at ways to control the structure and self-assembly of proteins that allow you to put them together to make a biocatalyst that looks a lot like a traditional heterogeneous catalyst used in the chemical-processing industry," Olsen says. "But instead of using transition metals, we want to use proteins, and enable the very effective enzymatic properties of proteins to be leveraged in chemical conversions."

"Biocatalysis is already a very active area in the pharmaceutical industry," he notes. "People also have been investigating this for applications such as biofuel synthesis and biofuel cells. Additionally, there are many potential applications in biosensing—in medicine, industrial practice, and detection of harmful compounds in the environment that are relevant to national security."

"Our group has many different efforts at the interface of natural and synthetic materials, trying to understand the fundamental science of bioinspired and biohybrid polymer systems and to bring these capabilities to bear on a wide variety of industrially and societally important challenges," Olsen says. "We hope that these new materials will lead to a more secure, healthier, and more sustainable world."

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