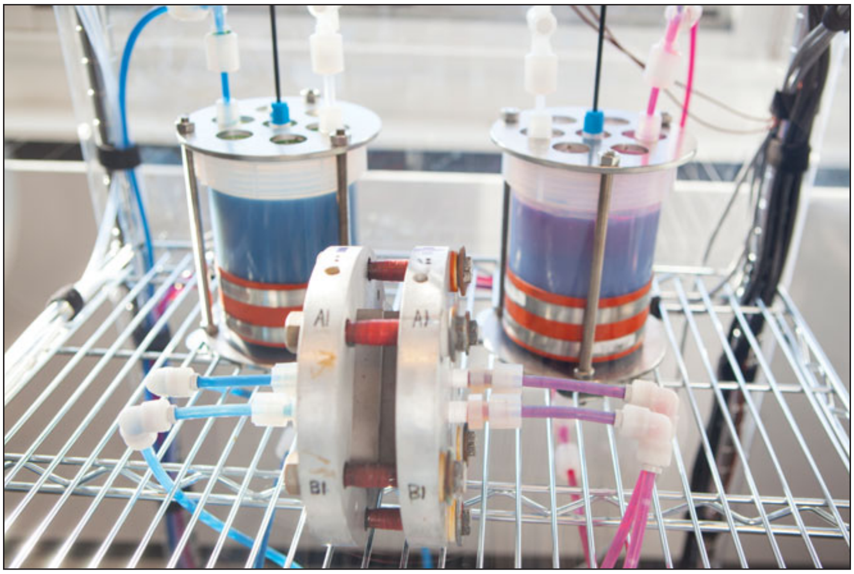

In this laboratory-scale organic molecule flow battery, energy-storing chemicals are dissolved in water and stored in containers in the background. To discharge the battery they are pumped through the energy conversion hardware in the foreground, converting chemical energy to electrical energy and becoming low-energy molecules. To recharge the battery, electrical energy is pushed into the energy-conversion hardware, converting low-energy chemicals into high-energy chemicals which are stored in these containers until electrical energy is needed again. The negative electrode is the left side of the battery and the positive electrode is the right side. In order to store more energy, the energy-conversion hardware does not need to change: only the container size and the amount of chemicals need to increase. Credit: Eliza Grinnell, Harvard School of Engineering and Applied Sciences.

expensive, and with no precious metal electrocatalysts.

"The whole world of electricity storage has been using metal ions in various charge states but there is a limited number that you can put into solution and use to store energy, and none of them can economically store massive amounts of renewable energy," said Roy G. Gordon, Thomas Dudley Cabot Professor of Chemistry and Professor of Materials Science at the Harvard School of Engineering and Applied Sciences (SEAS). "With organic molecules, we introduce a vast new set of possibilities. Some of them will be terrible and some will be really good. With these quinones we have the first ones that look really good."

Quinones are abundant in crude oil as well as in green plants, and the molecule the researchers used in their first quinone-based flow battery is almost identical to one found in rhubarb. The quinones are dissolved in water, which prevents them from catching fire.

Flow batteries store energy in chemical fluids contained in external tanks—as with fuel cells—instead of within the battery container itself. The two main components—the electrochemical conversion hardware through which the fluids are flowed (which sets the peak power capacity), and the chemical storage tanks (which set the energy capacity)—may be independently sized. Thus the amount of energy that can be stored is limited only by the size of the tanks. The design permits larger amounts of energy to be stored at a lower cost than with traditional batteries.

Team leader Michael J. Aziz, Gene and Tracy Sykes Professor of Materials and Energy Technologies at SEAS, said the next steps in the project will be to further test and optimize the system that has been demonstrated on the benchtop and bring it toward a commercial scale. "So far, we've seen no sign of degradation after more than 100 cycles, but commercial applications require thousands of cycles," he said. He also expects to achieve significant improvements in the underlying chemistry of the battery system. "I think the chemistry we have right now might be the best that's out there for stationary storage and quite possibly cheap enough to make it in the marketplace," he said. "But we have ideas that could lead to huge improvements."

Bio Focus

Contact lens elutes glaucoma medication sustainably for one month

Eye drops are relatively difficult to apply: one-sixth of glaucoma patients need assistance putting medicated eye drops into their eyes. Further, the eye drops can cause stinging and allergic reactions, and as glaucoma's symptoms can be subtle, patients often feel little motivation to take their medications. The resulting poor patient compliance can lead to irreversible blindness. While drug-eluting contact lenses were first proposed in the 1960s, poor drug release profiles have plagued prototypes.

Now, a team of Boston-based researchers led by Joseph Ciolino and Daniel Kohane of the Massachusetts Institute of Technology report, in the January issue of *Biomaterials* (DOI: 10.1016/j.biomaterials.2013.09.032; p. 432), a dual-polymer contact lens that releases therapeutic doses of the potent glaucoma medication latanoprost *in vivo* for a month. The device starts with methafilcon (a copolymer of methyl methacrylate and hydroxyethyl methacrylate). The researchers then spin-coat a solution of latanoprost and poly(lactic-*co*-glycolic acid) (PLGA) onto the methafilcon lens blank to produce 20-, 40-, or 45-µm-thick polymer-drug films. After solvent removal, a round aperture is incised in the center, and a topcoat of methafilcon is then

https://doi.org/10.1557/mrs.2014.38 Published online by Cambridge University Press

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applied to the donut-shaped translucent film. Finally, a lathe turns the cylindrical methafilcon-PLGA/latanoprost-methafilcon sandwich into a lens.

To track the *in vitro* drug release kinetics, the research team assayed daily aliquots of phosphate buffer solution (PBS) into which they had placed the lenses. After an initial burst, the latanoprost release rate steadied. The researchers also fitted lenses to rabbit eyes and periodically checked the concentration of latanoprost in the aqueous humor. The concentration of absorbed medication remained constant from the 3rd until the 28th day, after which time the lenses were removed. The latanoprost concentration in the aqueous humor was the same as for eye drop use.

Earlier studies by the research team demonstrated that both the PLGA and encapsulation within the polymer hydrogel contribute to the release kinetics. PLGA is FDA-approved; it biodegrades into components found naturally in the human body and has well-known release kinetics. The device's function is not materials-dependent, Kohane said. "Unlike other approaches where the drug was distributed throughout the lens, in our design there was a real advantage from its macroscopic nature. The larger an object is, the smaller its surface area to volume ratio and therefore the slower and more controlled its release is going to be. The key concept here is the design rather than the specific materials." While one concern for commercialization of the contact lens is degradation during storage, the PLGA can in principle be switched with a polymer with a longer shelf life.

Nor is the lens substrate materials-critical. In the long term the team may switch to contemporary silicone hydrogel lenses. For now they will try to increase the size of the film "window." Currently the aperture is equivalent to that of eye-color-changing contact lenses, but the researchers want the light transmission to be close to that of vision-correcting lenses.

"Here you have a contact lens that could be built with the patient's refractive correction, so that the patient would be seeing better using the lens.... Right now patients don't have much incentive to be compliant with their glaucoma medications. Glaucoma is commonly asymptomatic so most patients don't appreciate any vision loss until it's too late. So I think something that adds an incentive that is currently not there would be beneficial to improving compliance," said Ciolino.

Anuj Chauhan of the University of Florida uses vitamin E to slow contact lens drug release. "The strength of [the Boston] work is that you can release the medication for a month at zero-order release rates. Vitamin E is not zero order, it's diffusion-controlled. The advantage of the thin films is that you get close to zero-order release. Other methods have their own advantages, and it's good that multiple people are working on the problem."

Jen Gordon

Energy Focus

Skin pigment enables edible battery for biodegradable devices

By using the skin pigment melanin as an electrode material, researchers have made batteries that people could swallow. Such edible batteries could potentially power medical implants that disintegrate in the body instead of having to be surgically removed.

The idea behind biodegradable electronics is to make devices that go into the body, for example, to measure temperature, monitor wounds, or deliver drugs. Once their job is done, the devices could crumble into smaller pieces that are easily eliminated by the gastrointestinal tract, said Christopher Bettinger, a materials science and engineering professor at Carnegie Mellon University (CMU). "Unlike a pacemaker that has to last for five years, such edible electronics only need to last about 20 hours," he said. "So we want simple devices that are cheap and biocompatible."

Bettinger and others have already made biodegradable transistors and capacitors using various natural and synthetic materials. But the essential power sources for edible electronics were missing. Lithium-ion batteries could be used in the body if they are packaged safely, said Bettinger, but the toxic lithium and electrolytes in them could be a problem if the battery leaks or gets stuck in the body.

So he teamed up with materials science and engineering professor Jay Whitacre to use melanin electrodes in the sodium-ion battery chemistry that Whitacre has developed. Melanin shares some key properties with conventional electrode materials: it binds reversibly with ions, it generates electrons, and it is composed of uniform nanoscale granules that give it a very high surface area.

The sodium-ion battery relies on a water-based electrolyte to move sodium ions between its electrodes. The researchers replaced the activated carbon anode with those made of melanin. To make the anodes, they extracted melanin from cuttlefish, loaded it with sodium ions, and encased it in a steel mesh. The result is a battery that uses benign, abundant materials such as water, sodium, and melanin. "The cathode is manganese, which people need in their diets," Bettinger said. "We're using materials that are found in the body or that we eat anyway."

The battery could power a body temperature sensor for five hours, although its power output was less than that of a traditional battery. The melanin anodes, meanwhile, could provide as much current per mass as some well-known anode materials. Bettinger, Whitacre, W.J. Kim, and W. Wu of CMU and S.-E. Chun of the University of Oregon reported their results in the December 24 issue of the *Proceedings of the National Academy of Sciences* (DOI:10.1073/pnas.1314345110; p. 20912).

"This introduces a route to batteries built with biodegradable organic

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