New self-assembling material could be key to recyclable electric car batteries

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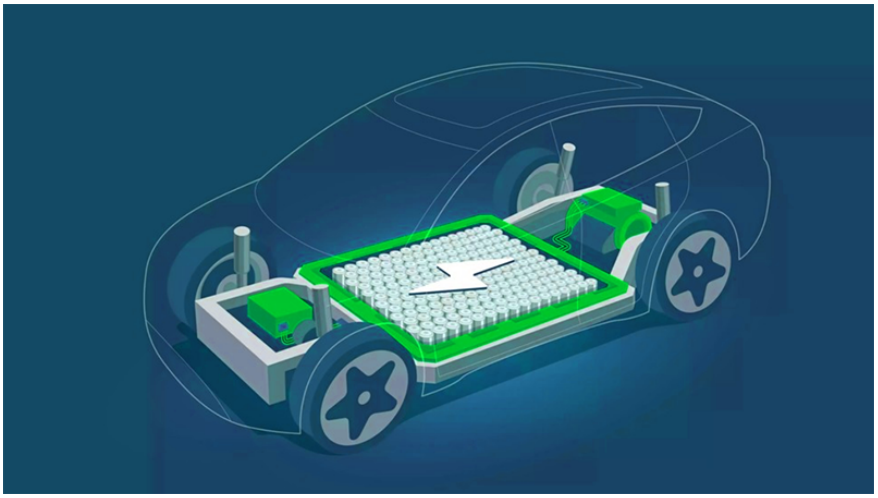
Researchers at MIT — short for Massachusetts Institute **of** Technology — have designed an electrolyte that can decompose at the end of a battery's life, allowing for easier recycling of components.

Today's electric vehicle boom is the e-waste mountain of the future. And while countless efforts are underway to improve battery recycling, many electric vehicle batteries still end up in landfills.

In that context, a research team from MIT wants to help change that with a new self-assembling battery material that can rapidly degrade when immersed in a simple organic liquid.

In a new paper published in the journal Nature Chemistry, the researchers show that the material can act as an electrolyte in a running solid-state battery cell and **then return to its original molecular components in just a few minutes.**



This method offers an alternative to crushing batteries into a jumbled mass that is difficult to recycle. Instead, because the electrolyte acts as the battery's connecting layer, the entire battery disassembles itself as the new material returns to its original molecular form, speeding up the recycling process.

'So far in the battery industry, we have focused on high-performance materials and designs, and only then tried to figure out how to recycle batteries that are made with complex structures and materials that are difficult to recycle,' said the paper's lead author, **Yukio Cho PhD** '23. 'Our approach is to start with materials that are easy to recycle and figure out how to make them compatible with batteries. Designing batteries with recyclability in mind from the start is a new approach.'

Also contributing to the paper with Cho are PhD student Cole Fincher, Ty Christoff-Tempesta PhD '22, Kyocera Professor of Ceramics Yet-Ming Chiang, Visiting Associate Professors Julia Ortony, Xiaobing Zuo, and Guillaume Lamour.

There is a scene in one of the 'Harry Potter' movies where Professor Dumbledore clears a ruined house with just a flick of his wrist and a spell. Cho says that image has been imprinted in his mind since he was a child.

When he saw a talk by Ortony about designing molecules so they could self-assemble into complex structures and then return to their original form, he wondered if that could be used to make battery recycling work like magic.

That would be a paradigm shift for the battery industry. Today's batteries require harsh chemicals, high temperatures, and complex processing to recycle. A battery has three main parts: the positively charged cathode, the negatively charged electrode, and the electrolyte that transports the lithium ions between them. The electrolyte in most lithium-ion batteries is highly flammable and over time decomposes into toxic byproducts that require specialized disposal.

To simplify the recycling process, the researchers decided to create a more sustainable electrolyte. To do so, they turned to a class of molecules that can self-assemble in water, called aramid amphiphiles (AAs), whose chemical structure and stability mimic that of Kevlar.

The researchers further engineered the AAs to contain polyethylene glycol (PEG), which conducts lithium ions, at one end of each molecule. When these molecules come into contact with water, they spontaneously form nanoribbons with ionically conductive PEG surfaces and bases, mimicking the strength of Kevlar through tight hydrogen bonding. The result is a mechanically stable nanoribbon structure that conducts ions across its surface.

'The material consists of two parts,' Cho explains. 'The first part is this flexible chain that creates a nest, or host, for the lithium ions to move around. The second part is a strong organic material component used in Kevlar, a bulletproof material. Those elements make the whole structure stable.'

When added to water, the nanoribbons self-assemble to form millions of nanoribbons that can be hot-pressed into a solid material.

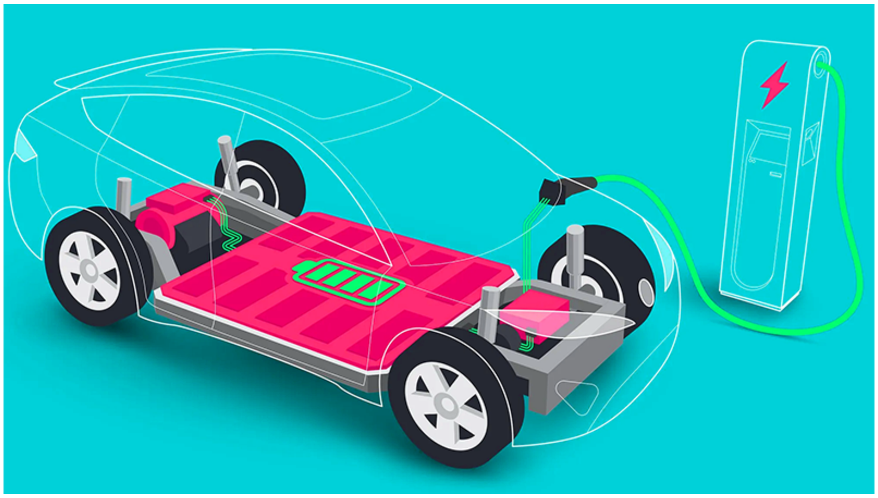
'Within five minutes of being added to water, the solution became gel-like, indicating that so many nanofibers had formed in the liquid that they started to intertwine with each other,' said Cho. 'What's exciting is that we can produce this material at scale thanks to the self-assembling behavior.'

The team tested the material's strength and toughness, finding that it could withstand the stresses involved in manufacturing and operating batteries. They also built a solid-state battery using lithium iron phosphate for the anode and lithium titanium oxide for the cathode, both of which are common materials in today's batteries. The nanoribbons successfully transported lithium ions between the electrodes, but a side effect called polarization limited the movement of lithium ions into the battery's electrodes during rapid charge and discharge cycles, hampering its performance compared to today's gold-standard commercial batteries.

'The lithium ions move along the nanowires quite well, but getting the lithium ions from the nanowires to the metal oxide seems to be the slowest point of the process,' says Cho.

When they dipped the battery pack into an organic solvent, the material immediately dissolved, with each part of the battery separating for easier recycling. Cho compared the material's reaction to cotton candy being dipped in water.

'The electrolyte holds the two electrodes of the battery together and provides pathways for the lithium ions,' says Cho. 'So when you want to recycle the battery, the whole electrolyte layer can fall off naturally and you can recycle the electrodes separately.'



Cho said the material is a proof of concept that demonstrates a recycling-first approach.

'We don't want to say we've solved all the problems with this material,' Cho said. 'Our battery performance isn't great because we're just using this material as the entire electrolyte for the paper, but what we envision is using this material as a layer in the battery electrolyte. It doesn't have to be the entire electrolyte to kickstart the recycling process.'

Cho also sees plenty of room to optimize the material's performance through further testing.

Researchers are now exploring ways to integrate these materials into existing battery designs as well as implementing the ideas into new battery chemistries.

'It's very difficult to convince existing suppliers to do something very different,' says Cho. 'But with new battery materials that could come out in the next five or ten years, it might be easier to integrate this into new designs from the start.'

Cho also believes this approach could help bring lithium supplies back home by reusing materials from batteries already available in the United States.

'People are starting to realize how important this is,' Cho said. 'If we can start recycling lithium-ion batteries from battery waste on a large scale, it would have the same effect as opening lithium mines in the United States. Also, each battery requires a certain amount of lithium, so if we extrapolate from the growth of electric vehicles, we need to reuse this material to avoid spikes in lithium prices.'

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