New material makes recycling a wide range of batteries simple and economical

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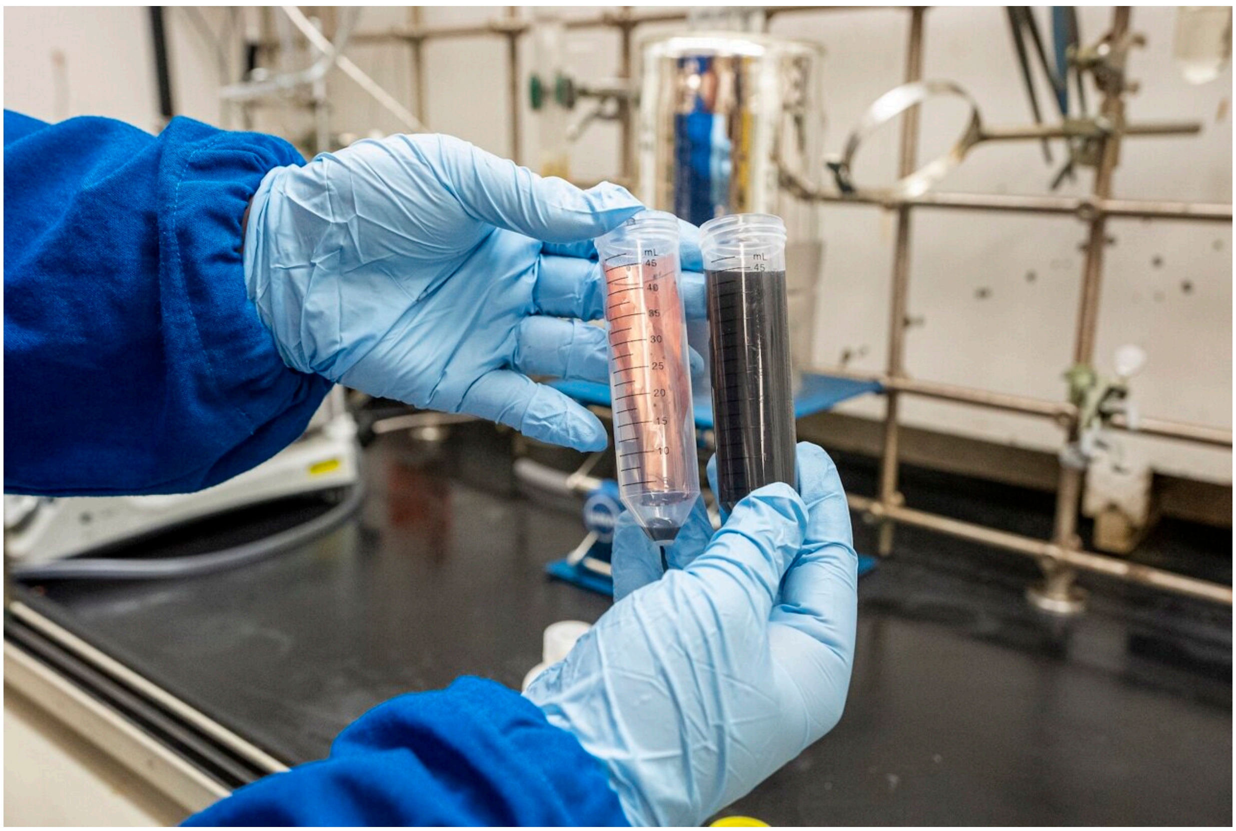

Chen Fang holds a vial (left) containing a current collector copper foil from a battery that has been completely freed of valuable electrode components after the Quick-Release Binder dissolved, and another vial (right) where the binder is actively dissolving in alkaline water. In comparison, conventional binders strongly bind electrode materials onto current collectors like a glue, which makes separation and thus recycling of battery electrode materials difficult. Credit: Marilyn Sargent/Berkeley Lab

Lithium-ion batteries have revolutionized electronics and enabled an accelerating shift toward clean energy. These batteries have become an integral part of 21st century life, but we're at risk of running out before 2050. The main elements used in each battery—lithium, nickel, and cobalt metals as well as graphite—are increasingly scarce and expensive, and there is little environmental or fair-labor oversight of some of the remaining international supply chains.

There is a pressing need to start reusing the materials we've already dug up and to make the battery production process safer and more equitable for all. A team of scientists from Lawrence Berkeley National Laboratory (Berkeley Lab) has invented an award-winning new battery material that can check both boxes. Their product, called the Quick-Release Binder, makes it simple and affordable to separate the valuable materials in Li-ion batteries from the other components and recover them for reuse in a new battery.

"We're getting to the point that recycling batteries will be a requirement," said project leader Gao Liu, a senior scientist in Berkeley Lab's Energy Technologies Area and a member of the Berkeley Lab Energy Storage Center. "If we don't stop burning them and throwing them in the trash, we will run out of resources in the next ten years. It's just impossible to keep up with the number of batteries the market is demanding otherwise. There's just not enough cobalt, not enough nickel—we have to recycle."

A battery made with Quick-Release Binder simply needs to be opened, placed in room temperature alkaline water, and gently shaken. The separated elements are easily filtered out of the water and air-dried.

It's a sharp contrast from current Li-ion recycling, which involves first shredding and grinding batteries, then burning them to separate the metals from the other constituents. Recycling companies aim to make their processes as efficient as possible, but due to the past and current design of most batteries, recovering the elements is still energy-intensive, expensive, and releases toxic chemicals that must be carefully managed.

Just add (alkaline) water

Liu and his team in the Berkeley Lab Energy Storage Center were working on lithium-sulfur batteries—one of the possible alternatives to traditional Li-ion that are being developed—when they created the Quick-Release Binder. Lithium-sulfur batteries are a hot concept in the battery research and development world because they can be made without rare cobalt and have a higher theoretical energy density than Li-ion; but there are a lot of functionality problems that must be solved before the batteries can be adopted commercially. The Quick-Release binder would make Li-S batteries easily recyclable and appears to solve one of the major performance issues. This finding is quite exciting on its own, but Chen Fang, a postdoctoral researcher in Liu's lab, realized that their new binder material had even bigger potential: it could also be used in today's Li-ion batteries.

Binders are glue-like substances used in most battery types, including Li-ion and the alkaline cells we use in household items. Batteries have two electrodes—the positively charged cathode and negatively charged anode—made of conductive chemicals that generate an electric current, and structural materials that hold the active ingredients in place for consistent and durable performance. Binders, as the name implies, bind these ingredients together and help maintain the architecture of the battery.

The new Quick-Release Binder is made from two commercially available polymers, polyacrylic acid (PAA) and polyethylenimine (PEI), that are joined together through a bond between positively charged nitrogen atoms in PEI and negatively charged oxygen atoms in PAA.

When the solid binder material is placed in alkaline water containing sodium hydroxide ($Na^{+}OH^{-}$), the sodium ion pops into the bond site, breaking the two polymers apart. The separated polymers dissolve into the liquid, freeing any electrode components embedded within.

The binder can be used to make anodes and cathodes, and is about one-tenth the price of two of the most commonly used commercial binders. "[In our recent research] we demonstrated that the whole process is very easy at the lab scale and we see no reason why it won't work equally well at the industrial scale," Fang said. He added that the team believes the material can be used for batteries of all sizes, from the small ones in cell phones to the extra-large batteries being deployed to store back-up energy on the nation's electric grid.

In late September, the technology was recognized by the R&D 100 Awards as one of the top 100 revolutionary technologies developed globally in 2022.

Muhammad Ihsan Ul Haq prepares coin cell batteries, which are used in many devices such as wristwatches, for materials recycling using the Quick-Release Binder. The team's tests show that the binder can work for a large range of battery types. Credit: Marilyn Sargent/Berkeley Lab

The team is now working with Steve Sloop, a battery recycling developer and founder of OnTo Technologies, to finish testing the product and bring it to the market. Past experiments demonstrated that the binder is highly stable at high and low voltages, and they now plan to build prototype Li-ion batteries with the binder to analyze its performance comprehensively and showcase its functionality.

If these tests go well, the scientists foresee a smooth transition to commercial manufacturing. "There's no fundamental obstacle in adapting the current manufacturing process to use the binder because it will actually simplify manufacturing for the same reason it simplifies recycling—you can use water instead of harsh solvents," said Chen. To make new batteries, manufacturers process binders with chemical solvents to create a slurry containing all the electrode components, which is then deposited in the desired shape and thickness on electrode sheets. "This means that current manufacturers need to set up extra instruments or facilities for protecting workers from toxic solvent vapor and for managing safe disposal of the solvent." The Quick-Release Binder would eliminate those steps.

Redesigning the battery lifecycle

According to Sloop, the Quick-Release Binder represents a paradigm shift in battery design. Instead of engineering advanced batteries and trying to create a recycling process after the fact, Liu's team was the first to "design for recycling."

"The binder has a great feature that it can be 'un-zipped' with low-cost, environmentally benign processing, which benefits us all by improving the economic and environmental sustainability of advanced battery systems," said Sloop. "It's also a great achievement that the batteries contain no perfluoroalkyl and polyfluoroalkyl substances (PFAS) —the family of compounds used to make non-stick coating and many other products, but it's extraordinarily important for the future. Customers don't want them due the emerging link with health issues, and I think soon regulators will agree that we can't keep using these chemicals."

Looking to the future, Liu and Sloop are meeting with battery companies and binder manufacturers to discuss commercialization. They hope to license the Quick-Release technology so it can be used in all the major Li-ion brands. Someday, the team's invention could be in all the batteries under our roofs and under our hoods—letting the remaining rare earth metals stay under the ground.

Provided by Lawrence Berkeley National Laboratory

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