Researchers look at novel methods to enhance battery performance

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Researchers are looking into ways to improve energy storage so they can better utilize renewable energy technologies. Credit: AdobeStock

Researchers at Penn State are looking at innovative ways to improve energy storage in an effort to better utilize renewable energy technologies.

"One of the primary obstacles stopping us from relying heavily on renewable energy systems is that we can't regulate when they provide us power," said Derek Hall, assistant professor of energy engineering at Penn State. "Ideally, we want to find some sort of energy storage technology that can complement renewables to help us transition to a more sustainable energy infrastructure."

Renewable energy systems, such as wind and solar, are capable of producing enough electricity to power entire communities. However, they rely on natural processes to produce the electricity needed, and nature can be unpredictable. This results in ebbs and flows in renewable electricity generation. At times, wind and solar are able to produce more than the grid can handle, driving electricity prices into the negative. Alternatively, if the wind stops or there is a period of poor weather, production halts and prices skyrocket.

This phenomenon inspired Hall to start exploring more cost-effective, energy storage strategies through multiple collaborative research projects at Penn State.

Enhancing battery chemistries

Hall, along with Christopher Gorski, associate professor of environmental engineering, and Serguei Lvov, professor of energy and mineral engineering and materials science and engineering and director of the Electrochemical Technologies Program at the EMS Energy Institute, are using ligand chemistry to enhance the electrochemical performance of cheaper battery chemistries, thanks to an Institutes of Energy and the Environment (IEE) and Materials Research Institute grant.

"The goal is to try to find cheaper materials to make batteries with," Hall said. "The main hurdle stopping us is that most cheap materials have small energy storage densities, which leads to poor battery performance."

Ligands are ions or molecules that bind to a central metal. They are commonly used in nature and biomimetic processes to alter metal reactivity, but they have not been previously used in flow batteries. The researchers are using materials such as copper, iron and chromium, which are cheaper than traditional materials such as lithium, cobalt and vanadium, and pairing them with ligands in an effort to significantly reduce the capital costs associated with producing batteries.

The team will then perform experiments to identify if the metal-ligand complexes achieve high energy storage densities. They will do this in three steps: thermodynamic, kinetic, and full cell testing. In each step, different key parameters will be tested for a typical redox flow battery. The thermodynamic phase will explore how the ligands impact the electrode potential, then the kinetic phase will test how much electrical current can be harnessed.

Finally, the researchers will test all the components together to see how they work in unison.

"A lot of parts to this story are still missing, so this will be largely a fundamental research project," Hall said. "There's no real unified theory explaining how ligands impact electrochemical reactions."

The researchers hope this project, titled "New Low-Cost Flow Battery Chemistries via Ligand-Enhanced Redox Reactions," will provide preliminary results needed to pursue larger grants aimed at developing new flow battery chemistries and gain fundamental insights into why and how ligands alter the reactivities of metal complexes.

"We need to start exploring all our options for energy storage because switching over our infrastructure to renewables is a major transition that is time sensitive," Hall said. "When we built our fossil fuel infrastructure, we did that over many decades. Now we need to figure out what the best choices, or most functional choices, are, and then build a whole lot of it really soon."

Converting waste heat into power

Hall is also working with Bruce Logan, professor of environmental engineering, and Matthew Rau, assistant professor of mechanical engineering, on research funded through another seed grant that looks to enhance the performance and the power output capabilities of flow batteries that are charged with waste heat rather than electricity.

"If we could find a way to redirect waste heat into electricity, even if it's a small amount on demand, this can help lessen our need for more electricity generation," Hall said.

Like with Hall's other project, this team is using a type of flow battery technology, but with a unique thermal recharging method. The project, titled "Increasing Power Densities and Cycle Efficiencies of Novel, Thermally-Charged Flow Batteries Using Advanced Flow Cell Topologies," will try to improve power density through distinctive battery flow field designs. They will do this through computational modeling using COMSOL Multiphysics software.

"The technology we're working on uses a specific chemical composition where you can recharge the chemical reaction using waste heat instead of electricity," Rau said.

In a traditional battery, a chemical reaction creates the discharge potential, generating electricity. When the process is reversed to recharge the battery, some electricity must be used to do so. For this new technology, the researchers will recharge the battery by separating two chemicals using waste heat. When those chemicals are combined back together, they will create a chemical reaction that generates electricity, therefore eliminating the need to use additional electricity to recharge the battery.

"This would be a competing technology to the traditional energy-storage methods, such as lithium ion batteries, but unique in the fact that it doesn't require electricity," Rau said. "It requires heat to charge, so we're essentially opening up a new resource that could potentially power industrial processes or part of the electrical grid."

The basic idea has been around roughly five years, Rau said, but the researchers are looking to improve the performance of the basic model, so that it can become commercially viable.

"Developing this technology will not be easy," he said. "These batteries flow electrolytes through porous electrodes. The fluid flow alone is complicated enough to model without even considering the chemical reactions also occurring. We are developing the expertise to accurately model how the fluid flow in these batteries affects the different chemical reactions and ultimately how these parameters relate to the battery power output."

The researchers are hopeful that preliminary experiments done prior to starting this study have given them the tools needed for success.

"We currently have little use for waste heat in industry and in power generation," Rau said. "It just gets discarded with the cooling water or spewed into the atmosphere in an exhaust stack. If we can actually harness that the waste heat, we'll increase the energy efficiency of many different industries."

These projects illustrate the need to develop large-scale, energy storage technologies that pair well with renewable energy technologies, Hall said.

"There's not going to be one solution that just wins out," he added. "It will likely be a mix. It's sort of an all-hands-on-deck situation. We really don't know which one is going to work out or when it will be needed, so I think exploring multiple options is the best way forward."

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