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Upgrading the vanadium redox battery

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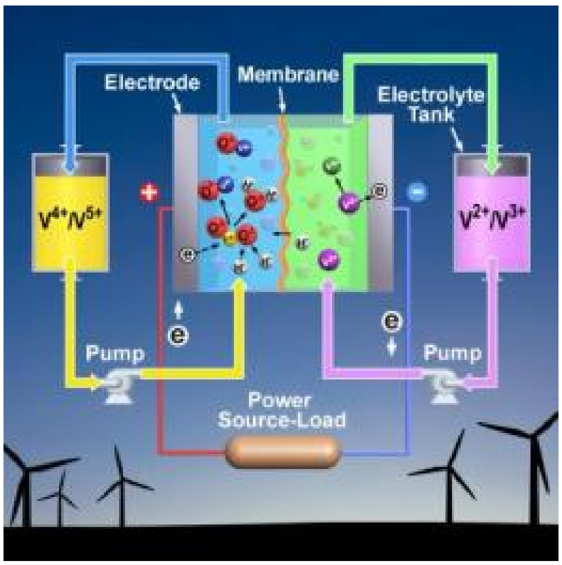

This artist's rendering of an upgraded vanadium redox battery shows how using both hydrochloric and sulfuric acids in the electrolyte significantly improves the battery's performance and could also improve the electric grid’s reliability and help connect more wind turbines and solar panels to the grid. Credit: Pacific Northwest National Laboratory

Though considered a promising large-scale energy storage device, the vanadium redox battery's use has been limited by its inability to work well in a wide range of temperatures and its high cost. But new research indicates that modifying the battery's electrolyte solution significantly improves its performance. So much so that the upgraded battery could improve the electric grid's reliability and help connect more wind turbines and solar panels to the grid.

In a paper published by the journal *Advanced Energy Materials,* researchers at the Department of Energy's Pacific Northwest National Laboratory found that adding hydrochloric acid to the sulfuric acid typically used in vanadium batteries increased the batteries' energy storage capacity by 70 percent and expanded the temperature range in which they operate.

"Our small adjustments greatly improve the vanadium redox battery," said lead author and PNNL chemist Liyu Li. "And with just a little more work, the battery could potentially increase the use of wind, solar and other renewable power sources across the electric grid."

Unlike traditional power, which is generated in a reliable, consistent stream of electricity by controlling how much coal is burned or water is sent through dam turbines, renewable power production depends on uncontrollable natural phenomena such as sunshine and wind. Storing electricity can help smooth out the intermittency of renewable power while also improving the reliability of the electric grid that transmits it. Vanadium batteries can hold on to renewable power until people turn on their lights and run their dishwashers. Other benefits of vanadium batteries include high efficiency and the ability to quickly generate power when it's needed as well as sit idle for long periods of time without losing storage capacity.

A vanadium battery is a type of flow battery, meaning it generates power by pumping liquid from external tanks to the battery's central stack, or a chamber where the liquids are mixed. The tanks contain electrolytes, which are liquids that conduct electricity. One tank has the positively-charged vanadium ion V^{5+} floating in its electrolyte. And the other tank holds an electrolyte full of a different vanadium ion, V^{2+}. When energy is needed, pumps move the ion-saturated electrolyte from both tanks into the stack, where a chemical reaction causes the ions to change their charge, creating electricity.

To charge the battery, electricity is sent to the vanadium battery's stack. This causes another reaction that restores the original charge of vanadium ions. The electrical energy is converted into chemical energy stored in the vanadium ions. The electrolytes with their respective ions are pumped back into to their tanks, where they wait until electricity is needed and the cycle is started again.

A battery's capacity to generate electricity is limited by how many ions it can pack into the electrolyte. Vanadium batteries traditionally use pure sulfuric acid for their electrolyte. But sulfuric acid can only absorb so many vanadium ions.

Another drawback is that sulfuric acid-based vanadium batteries only work between about 50 and 104 degrees Fahrenheit (10 to 40 Celsius). Below that temperature range, the ion-infused sulfuric acid crystallizes. The larger concern, however, is the battery overheating, which causes an unwanted solid to form and renders the battery useless. To regulate the temperature, air conditioners or circulating cooling water are used, which causes up to 20 percent energy loss and significantly increasing the battery's operating cost, the researchers noted.

Wanting to improve the battery's performance, Li and his colleagues began searching for a new electrolyte. They tried a pure hydrochloric acid electrolyte, but found it caused one of the vanadium ions to form an unwanted solid. Next, they experimented with various mixtures of both hydrochloric and sulfuric acids. PNNL scientists found the ideal balance when they mixed 6 parts hydrochloric acid with 2.5 parts sulfuric acid. They verified the electrolyte and ion molecules present in the solution with a nuclear magnetic resonance instrument and the Chinook supercomputer at EMSL, DOE's Environmental Molecular Sciences Laboratory at PNNL.

Tests showed that the new electrolyte mixture could hold 70 percent more vanadium ions, making the battery's electricity capacity 70 percent higher. The discovery means that smaller tanks can be used to generate the same amount of power as larger tanks filled with the old electrolyte.

And the new mixture allowed the battery to work in both warmer and colder temperatures, between 23 and 122 degrees Fahrenheit (-5 to 50 Celsius), greatly reducing the need for costly cooling systems. At room temperature, a battery with the new electrolyte mixture maintained an 87 percent energy efficiency rate for 20 days, which is about the same efficiency of the old solution.

The results are promising, but more research is needed, the authors noted. The battery's stack and overall physical structure could be improved to increase power generation and decrease cost.

"Vanadium redox batteries have been around for more than 20 years, but their use has been limited by a relatively narrow temperature range," Li said. "Something as simple as adjusting the batteries' electrolyte means they can be used in more places without having to divert power output to regulate heat."

More information: Liyu Li, Soowhan Kim, Wei Wang, M. Vijaayakumar, Zimin Nie, Baowei Chen, Jianlu Zhang, Guanguang Xia, Jianzhi Hu, Gordon Graff, Jun Liu, Zhenguo Yang. A Stable Vanadium Redox-Flow Battery with High Energy Density for Large-Scale Energy Storage. *Advanced Energy Materials.* Published online March 11, 2011. onlinelibrary.wiley.com/doi/10 … m.201100008/abstract

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