Solar+battery in one device sets new efficiency standard

Enlarge / Existing solar+battery solutions involve two separated pieces of hardware.

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The drop in battery prices is enabling battery integration with renewable systems in two contexts. In one, the battery serves as a short-term power reservoir to smooth over short-term fluctuations in the output of renewable power. In the other, the battery holds the power for when renewable power production stops, as solar power does at night. This works great for off-grid use, but it adds some complications in the form of additional hardware to convert voltages and current.

But there’s actually an additional option, one that merges photovoltaic and battery hardware in a single, unified device that can have extensive storage capacity. The main drawback? The devices have either been unstable or have terrible efficiency. But an international team of researchers has put together a device that’s both stable and has efficiencies competitive with those of silicon panels.

Solar flow batteries

How do you integrate photovoltaic cells and batteries? At its simplest, you make one of the electrodes that pulls power out of the photovoltaic system into the electrode of a battery.

Which sounds like a major “well, duh!” But integration is nowhere near that simple. Battery electrodes, after all, have to be compatible with the chemistry of the battery—for lithium-ion batteries, for example, the electrodes end up storing the ions themselves and so have to have a structure that allows that.

So, the researchers used a completely different sort of chemistry. Flow batteries use solutions of two chemicals that can undergo charge-exchange reactions, shifting them between two chemical states. The battery basically borrows those charges in order to produce current when discharging, or it pumps charges back in to shift the chemicals to their alternate state, thus charging the battery. Flow batteries have the advantage that their total storage capacity is simply dependent upon the total volume of solution you use.

While there are many chemistries capable of working in a flow battery, the researchers started with their photovoltaic system and used that to choose the battery’s chemistry.

Even here, they didn’t exactly use off-the-shelf hardware. There was silicon involved, but it was part of a two-layer solar cell. In this setup, one photovoltaic material absorbs a set of wavelengths that aren’t absorbed by a second; the first layer, in contrast, is transparent to those wavelengths absorbed by the second. This allows a single cell to absorb a much broader range of wavelengths than would be possible otherwise, upping its overall efficiency.

For their device, the bottom layer was silicon. On top of that is a layer of perovskite photovoltaic material. Perovskites are a potential next-generation solar material, useful because they’re made from cheap ingredients and can be created simply by evaporating a solution of the perovskite. Unfortunately, these chemicals also have a propensity to decay, which has made for short lifetimes in many experimental setups. The researchers here don’t try to solve all these problems; they

simply use a perovskite-on-silicon photovoltaic setup and don’t try to run it for long enough that chemical decay is an issue.

Putting pieces together

The key concept the researchers had was to start with this photovoltaic material and match the battery chemistry to its properties. Photovoltaic cells have a voltage, based on the bandgap (the voltage difference between the insulating and conducting states of their electrons) of the materials they’re made of. Batteries also have a potential measured in volts, based on the energy difference between the two chemical states that power them. Match these voltages, the researchers reasoned, and you’d get a far more efficient system.

So, using data on their photovoltaic hardware, they were able to identify a flow-battery chemistry with a potential that matched its voltage. (The actual chemistry involves reactions between two different organic molecules, bis-(trimethylammonio)propyl viologen and 4-trimethylammonium-TEMPO. Since I’m sure you were going to ask.) The reactions that take these chemicals between their two states are fast enough that they occur in the absence of catalysts, which simplifies the use of electrodes.

Which is important, given that another problem with flow batteries is that their chemicals tend to also react with many photovoltaic materials, which would cut down on the lifespan of these devices rather dramatically. So, the researchers covered the silicon with a thin layer of gold, which was both conductive and inert. Obviously, a cheaper inert metal would be preferred if this were to go into widespread production.

The resulting hardware can operate in any of three modes: providing power as a solar cell, using sunlight to charge as a battery, or providing power as a battery.

SOEE

Previous records for a solar flow battery show the tradeoffs these devices have faced. The researchers used a measure of efficiency termed solar-to-output electricity efficiency, or SOEE. The most efficient solar flow devices had hit 14.1 percent but had short lifespans due to reactions between the battery and photovoltaic materials. More stable ones, which had lifespans exceeding 200 hours, only had SOEEs in the area of 5 to 6 percent.

The new material had an SOEE in the area of 21 percent—about the same as solar cells already on the market, and not too far off the efficiency of the photovoltaic hardware of the device on its own. And their performance was stable for over 400 charge/discharge cycles, which means for at least 500 hours. While they might eventually decay, there was no indication of that happening over the time they were tested. Both of those are very, very significant improvements.

Obviously, given that both batteries and photovoltaic cells can potentially last for decades, 500 hours shouldn’t be viewed as a definitive test—especially for a device that’s proposed to enable off-the-grid electrical production. But the demonstration that voltage matching provides such a large efficiency boost should allow researchers to identify a wider range of battery and photovoltaic chemistries that have improved efficiencies. That accomplished, researchers will then be able to search among those for stable configurations. Whether all of that is compatible with low cost and mass production will be the critical question. But, at this stage of the renewable energy revolution, having more options to explore can only be a good thing.

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