Solution to energy storage may be beneath your feet

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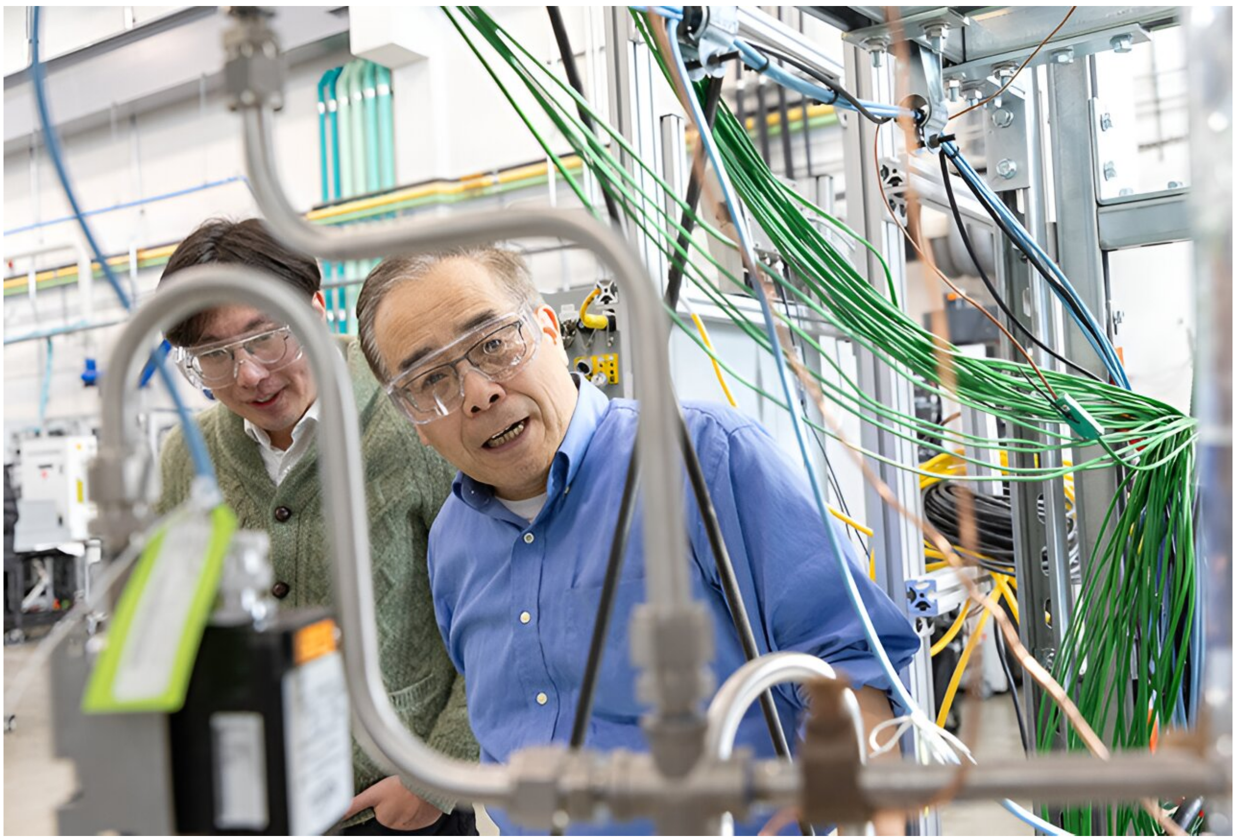

Researchers Shin Young Jeong and Zhiwen Ma examine the prototype device that uses superheated sand for long-duration energy storage. Credit: Joe DelNero, NREL

Anyone who has ever hot-footed it barefoot across the beach on a sunny day walks away with a greater understanding of just how much heat sand can retain. That ability is expected to play a vital role in the future, as technology involving heated sand becomes part of the answer to energy storage needs.

Batteries are likely what most people think about in terms of storing energy for later use, but other technologies exist. Pumped storage hydropower is one common method, albeit one that requires reservoirs at different elevations and is limited by geography. Another approach relies on what is known as thermal energy storage, or TES, which uses molten salt or even superheated rocks.

TES shows promise as a low-cost alternative to existing storage technologies, and storing energy in solid particles such as sand provides a ready answer, without geological restrictions.

After all, sand, like air and water, is everywhere.

"Sand is easy to access. It is environmentally friendly. It is stable, quite stable, in a wide temperature range. It is also low cost," said Zhiwen Ma, a mechanical engineer in the laboratory's Thermal Energy Systems Group.

The need for long-term storage

Patented technology developed and prototyped at NREL reveals how heaters powered by renewable energy sources like wind and solar can raise the temperature of sand particles to the desired temperature. The sand is then deposited into a silo for storage and use later, either to generate electricity or for process heat in industrial applications. A laboratory-scale prototype validated the technology and allowed researchers to create a computer model that shows a commercial-scale device would retain more than 95% of its heat for at least five days.

"Lithium-ion batteries have really cornered the market at two to four hours of storage, but if we want to achieve our carbon reduction goals, we will need long-duration energy storage devices—things that can store energy for days," said Jeffrey Gifford, a postdoctoral researcher at NREL.

Gifford, who already shares two patents with Ma on heat exchangers that convert stored thermal energy to electricity, said the use of sand or other particles to store thermal energy has another advantage over batteries. "Particle thermal energy storage doesn't rely on rare-earth materials or materials that have complex and unsustainable supply chains. For example, in lithium-ion batteries, there are a lot of stories about the challenge of mining cobalt more ethically."

In addition to TES, Gifford's expertise is in computational fluid dynamics. That knowledge is important because the sand needs to flow through the storage device. Other TES media includes concrete and rocks, which can easily retain heat but remain solidly in place. "Your heat transfer is much higher and much quicker and much more effective if you're moving your media," Gifford said.

TES also has another key advantage: the cost. Ma has calculated sand is the cheapest option for energy storage when compared to four rival technologies, including compressed air energy storage (CAES), pumped hydropower, and two types of batteries. CAES and pumped hydropower can only store energy for tens of hours.

The cost per kilowatt-hour for CAES ranges from $150 to $300, while for pumped hydropower it is about $60. A lithium-ion battery would cost $300 a kilowatt-hour and only have a capacity to store energy from one to four hours. With a duration lasting hundreds of hours, sand as a storage medium would cost from $4 to $10 a kilowatt-hour. To ensure low cost, the heat would be generated using off-peak, low-price electricity.

Ma, who holds a handful of patents on the technology, previously served as the principal investigator on an ARPA-E funded project known as ENDURING, for Economic Long-Duration Electricity Storage by Using Low-Cost Thermal Energy Storage and High-Efficiency Power Cycle. The prototype came from this project.

Next up is the groundbreaking in 2025 on an electric thermal energy storage (ETES) system at NREL's Flatirons Campus outside Boulder, Colorado, that will be designed to store energy for between 10 and 100 hours. The stand-alone system is free from any siting restrictions that limit where CAES or pumped storage hydropower can be established.

The DOE-funded demonstration project, Ma said, is intended to show the commercial potential of sand for TES.

Molten salts are already in use to temporarily store energy, but they freeze at about 220°C (428°F) and start to decompose at 600°C. The sand Ma intends to use comes out of the ground in the Midwest of the United States, does not need to be kept from "freezing," and can retain considerably more heat, in the range of 1,100°C (2,012°F) that can store heat for power generation or to replace burning fossil fuels for industrial heat.

"This represents a new generation of storage beyond molten salt," Ma said.

Deciding what will store the heat

But will just any old sand do? Not according to NREL researchers, who examined various solid particles for their ability to flow and to retain heat. In a paper published last fall in *Solar Energy*, Ma and others experimented on eight solid particle candidates. Among the particles considered were man-made ceramic materials used in fracking, calcined flint clay, brown fused alumina, and silica sand. The clay and fused alumina were rejected because of thermal instability at the target temperature of 1,200°C (2,192°F).

The ceramic materials outperformed the sand in all categories, but the marginal performance gains were considered insufficient to justify the higher cost. While the sand costs from $30 to $80 a ton, the prices of the ceramic materials were about two magnitudes higher. The sand is in the ultra-pure form of alpha quartz and readily available in the Midwest.

Expanding the amount of energy that can be stored in sand is as simple as adding more sand, said Craig Turchi, manager of the Thermal Energy Science and Technologies Research Group at NREL.

"That's a marginal cost to add additional storage capacity," he said. "We need storage ranging from minutes to months. Batteries worked really well in the minutes to hours space in terms of how they scale. And when you get into months of storage, you're usually looking at making a fuel like hydrogen to provide that long-term storage. But in the period between multiple hours and two weeks, there's not a good fit right now. Hydrogen is too expensive for that. Batteries are too expensive for that."

The components needed to convert the superheated sand back to electricity does require an upfront cost. "But once you've paid for that," Turchi said, "if you just want to have more duration for your power it's much, much cheaper to add more sand than the alternative, which is to keep adding batteries."

More information: Patrick Davenport et al, Characterization of solid particle candidates for application in thermal energy storage and concentrating solar power systems, *Solar Energy* (2023). DOI: 10.1016/j.solener.2023.111908

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