Using the sun’s heat to make electricity

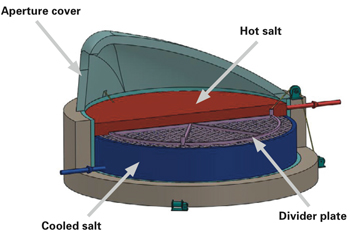
An MIT team has developed a novel system for capturing and storing the sun’s heat so it can be used to generate electricity whenever it’s needed. The new system is simple, durable, and inexpensive. Mirrors mounted on a hillside reflect sunlight directly into a large tank of molten salt, which absorbs the heat throughout its depth. The system can handle the intense power of the midday sun as well as temperature changes throughout the day and night without structural failure or interruptions in power production. Modeling studies and lab-scale experiments confirm the viability of the concept and the availability of extensive hilly areas suitable for installations. Teams from MIT and the Masdar Institute are now developing a pilot-scale version of the system that will soon be tested at a major experimental facility at Masdar.

Many commercial-scale plants now produce electricity using the heat of the sun—our most abundant renewable energy source. In one popular approach, large arrays of heliostats (sun-tracking mirrors) reflect sunlight to the top of a centrally located tower, where it’s focused on tubes carrying heat-absorbing fluid. The heated fluid is then pumped to a steam generator, where it converts water into steam that drives an electricity-generating turbine. But the tower is costly; the piping and pumps are expensive to install and run; and the intensely focused sunlight and the constant cycling between hot and cold challenge most materials. In addition, these “power towers” generally require a separate system to store heat to use when sunlight isn’t available.

To [Alexander Slocum](https://energy.mit.edu/news/using-the-suns-heat-to-make-electricity/), the Pappalardo Professor of Mechanical Engineering, it seemed that there had to be a better way. Motivated by that belief, he and an interdisciplinary team of colleagues at MIT and the Masdar Institute in Abu Dhabi are now bringing a novel bench-scale system developed by the MIT participants to the next level of testing—at a large-scale experimental facility at Masdar. The system—called CSPonD, for “Concentrated Solar Power on Demand”—both captures and stores the sun’s thermal energy, for the most part utilizing known technological elements energetically combined in a new system architecture.

At the core of the CSPonD system is a large tank (illustrated below) that contains molten salt—a substance that can handle extremely high temperatures and has a huge capacity for absorbing heat. An array of heliostats is situated on a hillside, the tank of salt at the foot of the hill. The heliostats focus the sunlight through a small opening in the tank directly onto the surface of the salt (see second diagram below), where it penetrates the salt and is absorbed throughout its depth. Natural convection disperses the heat through the entire volume of molten salt. During power generation, hot salt is withdrawn from the top and passed through a steam generator; cold, but still molten, salt leaving the steam generator is returned to the bottom of the tank. A movable “divider plate” between the top and bottom regions maintains the upper volume of salt at a constant temperature. At night or when it’s cloudy, doors close to reduce heat loss.

CSPonD molten salt receiver/storage system



This diagram shows the large tank of molten salt that is central to the CSPonD system. Sun-tracking mirrors (heliostats) focus sunlight directly through the aperture at the left onto the surface of the salt. Hot salt is withdrawn from the top of the tank and passed through a steam generator for power production. The cooled (but still molten) salt is returned to the bottom of the tank. A movable divider plate at the center of the tank keeps the hot and cold salt separate. As salt is heated on a sunny day, the plate moves down in the tank to make room for more hot salt. When sunlight is unavailable, the plate moves up, making space for the cold salt coming from the steam generator. When the sun returns, the plate moves down, allowing cold salt to pass into the upper region for reheating. At night, the aperture cover is closed to prevent heat from escaping.

This arrangement provides a number of advantages. The sun’s energy encounters the working fluid directly— no tubes are needed—and the salt can reach 600°C or even 800°C, which is hot enough for highly efficient power production with either today’s most advanced steam systems or future ultra-efficient systems using supercritical carbon dioxide. Because heat is absorbed throughout the molten salt, temperature swings aren’t abrupt or extreme, so there’s no need to use costly materials that can tolerate all the energy the sun delivers at midday. “You can focus intense sunlight, and you’re not going to burn up the receiver because you can’t hurt the salt,” says Slocum. And the simple salts the team plans to use are well-known in industry. For the past century, companies worldwide have heat-treated steel by submerging it in large open vats of hot salt—similar to the CSPonD tank—and molten salt is regularly used as a heat-transfer fluid in industrial plants.

Finally, the new design can deal with deposits of dust and dirt. When a dust storm brews, the cover on the CSPonD tank can be closed. Any dirt that does land on the molten salt will sink to the bottom where it can be removed later during periodic cleanouts—just the way molten salt tanks are periodically cleaned in industry. Buildup of dust on the heliostat mirrors is still a concern, as with any solar energy system; but in the short term, the heliostat array can be oversized to ensure that production meets demand—even between cleanings. And unlike conventional systems, CSPonD can handle whatever sunlight is delivered when the mirrors are freshly cleaned and reflecting at full power. In the longer term, better self-cleaning surfaces are apt to be brought to market, especially if demand arises.

Designed for storage

Ensuring that the top layer of hot salt is always available for power production requires keeping the returning cold salt in its place—at the bottom of the tank. Most commercial heat-storage systems prevent mixing by using individual hot and cold tanks connected by hoses and pumps. But the CSPonD system separates hot and cold within the single tank.

A horizontal divider plate (shown in the first figure) is placed in the tank with a gap between its edge and the tank wall. Small actuators (with negligible power consumption) move the loose-fitting, mostly buoyant divider plate up and down to maintain the hot and cold salt volumes required for continuous operation. As sunlight heats the salt, the divider plate is lowered, and cold salt from below moves upward through the gap to be heated. Thus, at the end of a sunny day, the divider plate has moved down, and the hot salt region is fully charged. When sunlight is no longer available and heat is being extracted to produce electricity, the divider plate is slowly raised to allow the cold zone to refill while hot salt is supplied to the steam generator. When sunshine returns, the plate once again descends, allowing cold salt to rise for reheating. Careful control of the plate’s position ensures that the hot salt remains at a constant temperature, in effect balancing the solar energy input with the energy that’s extracted and stored.

Modeling results, experimental evidence

As an initial test of their concept, the researchers simulated the performance of a CSPonD system that included a tank that’s 5 meters deep, 25 meters in diameter, and filled with 4,500 tons (2,500 cubic meters) of molten salt at 600°C. The analysis concluded that the specified system could power a 4 megawatt-electric (MWe) steam turbine 24/7 (based on 7 hours of sunshine and 17 hours of storage)— enough electricity to supply about 2,000 homes. Modest oversizing of the heliostat field to accumulate more solar energy would enable the system to operate for an additional 24 hours (one cloudy day).

An economic analysis using a model from the National Renewable Energy Laboratory concluded that the levelized cost of electricity from the CSPonD system would be between $0.07 and $0.33 per kilowatt-hour. While the higher estimate is currently prohibitively high, the lower estimate would be competitive with the cost of electricity from conventional power sources today. Research now under way will help to better elucidate the actual costs.

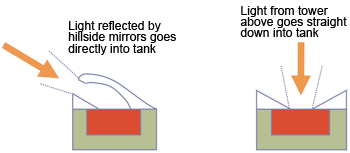
The practical feasibility of CSPonD does, of course, hinge on the availability of appropriate hills for heliostat installations. How large would the hills need to be, and would suitable sites be hard to locate? To find out, researchers led by Alexander Mitsos, former assistant professor of mechanical engineering at MIT and now professor of chemical engineering at RWTH Aachen University in Germany, developed a novel algorithm that identifies potential sites using data on topography, solar insolation, and other conditions plus a model of CSPonD system operation.

They then performed two case studies focusing on government military bases at White Sands, New Mexico, and China Lake, California. The analyses showed that 15% of the total 10,000 square kilometers of land at the two bases would be appropriate for CSPonD installations. With 30% of that available land covered by heliostats, installations at each site could continuously generate 20 gigawatts of power. “So those two bases together could provide 40 gigawatts of power, which is somewhere around 4% of the nation’s electric need,” says Slocum. “And that’s just using a little piece of all the hillsides that they have.” Slocum adds: “The Army Corps of Engineers is responsible for our nation’s seacoasts and waterways to keep commerce flowing and protect our way of life at home, and it makes sense that vast government lands also be used to protect our energy security and combat climate change.”

While installing heliostats on hillsides isn’t standard procedure, Slocum isn’t concerned. “We may need to design and create custom equipment to drive up the sides of hills, popping in heliostats,” he says. “But companies have been designing amazing forestry machines that go up much steeper slopes for decades. It’s not an issue for the scale of systems that will be needed.”

Initial bench-scale experiments indicate that the CSPonD concept is technically sound. For example, in one set of tests, the researchers showed that concentrated sunlight will indeed penetrate and be absorbed by molten salt through a depth of 4 to 5 meters—enough for the CSPonD system to be unperturbed by changes in solar insolation due to passing clouds. In other tests, they designed and built a small-scale CSPonD tank equipped with a movable divider plate and then shone light from a high-flux solar simulator onto the molten salt inside. They found that natural convection in the upper region promotes mixing, keeping the top surface from overheating while maximizing thermal storage in a given volume of salt. And the submerged divider plate successfully separates the hot and cold salt volumes as needed for continuous operation.

CSPonD tank configurations



The researchers have designed two versions of the CSPonD tank suited to particular sites. Left: In this version, heliostats mounted on a hillside reflect sunlight into a tank below. The sunlight passes through the aperture in the tank directly onto the salt inside. Right: At Masdar’s experimental “beam-down” facility, mirrors on the central tower will reflect sunlight directly down through the aperture into the CSPonD tank.

Next steps

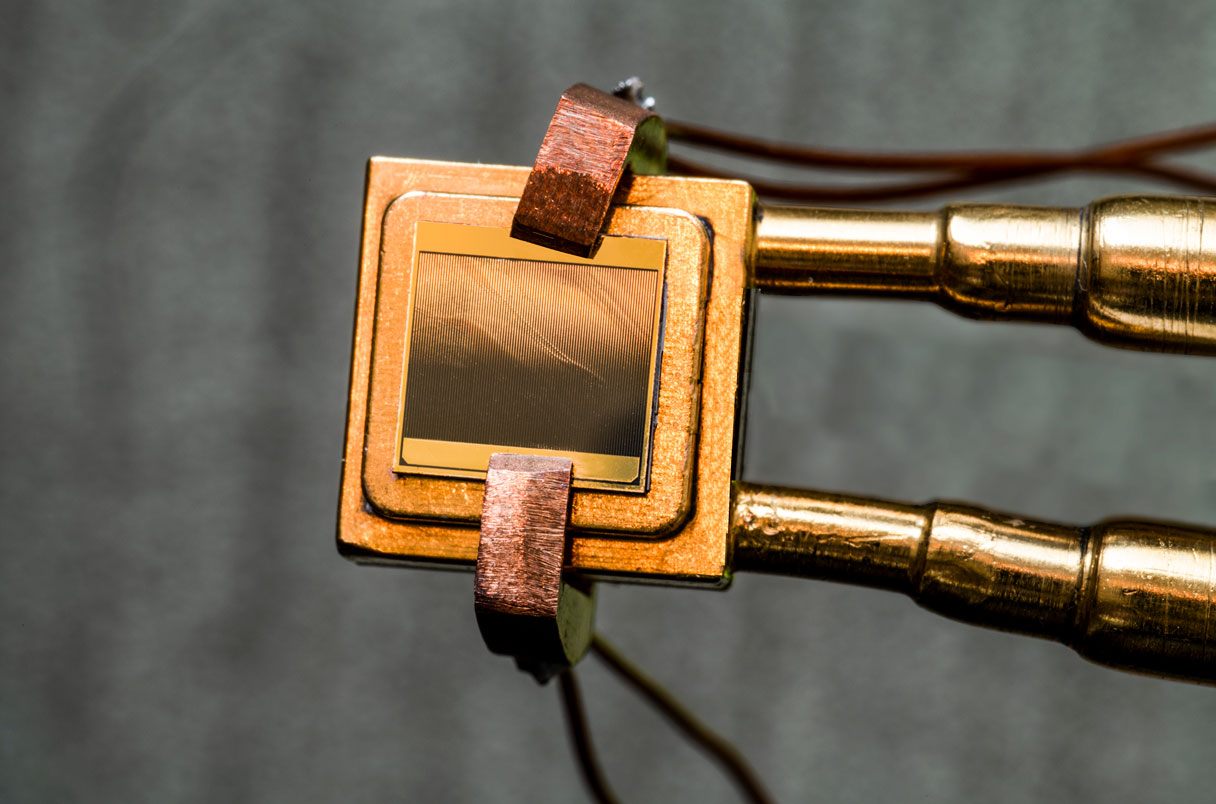
To test the CSPonD concept at larger scale, the MIT researchers have started work with colleagues at the Masdar Institute who operate a major experimental “beam-down facility” that includes 33 heliostats and a 66-foot tower with mirrors that reflect sunlight down into a central receiver. In upcoming work, the researchers will replace the receiver with a small CSPonD system. The heliostats will focus sunlight directly down into the tank (see the second diagram). The initial small-scale system will store enough thermal energy for 25 kilowatt-hours of power generation. “We’re going to use it to test our design theories and practical implementation issues,” says Slocum. “Then in the next step we can scale up to a much larger machine.”

Slocum stresses that he doesn’t dismiss other solar technologies and feels diversity is the key to robustness and continual innovation. Indeed, he praises photovoltaic and solar thermal systems “of various flavors” and notes in particular that everyone should at least have a rooftop solar hot water system. But CSPonD may be the best choice for certain locations and thus is a valuable addition to what Slocum calls a “well-balanced diet of options for feeding humanity’s ever-growing energy appetite.”

# ‘Thermal batteries’ could efficiently store wind and solar power in a renewable grid

## Stored as heat in a bath of molten material, extra energy could be tapped when needed

* 13 APR 2022
* 11:00 AM
* BY[ROBERT F. SERVICE](https://www.science.org/content/author/robert-f-service)

A thermophotovoltaic cell turns furnacelike heat into electricity.FELICE FRANKEL

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[**Table of contents**](https://www.science.org/toc/science/376/6590)

A version of this story appeared in Science, Vol 376, Issue 6590.[Download PDF](https://www.science.org/doi/epdf/10.1126/science.abq4275)

How do you bottle renewable energy for when the Sun doesn’t shine and the wind won’t blow? That’s one of the most vexing questions standing in the way of a greener electrical grid. Massive battery banks are one answer. But they’re expensive and best at storing energy for a few hours, not for days long stretches of cloudy weather or calm. Another strategy is to use surplus energy to heat a large mass of material to ultrahigh temperatures, then tap the energy as needed. This week, researchers report a major improvement in a key part of that scheme: a device for turning the stored heat back into electricity.

A team at the Massachusetts Institute of Technology (MIT) and the National Renewable Energy Laboratory achieved a nearly 30% jump in the efficiency of a thermophotovoltaic (TPV), a semiconductor structure that converts photons emitted from a heat source to electricity, just as a solar cell transforms sunlight into power. “This is very exciting stuff,” says Andrej Lenert, a materials engineer at the University of Michigan, Ann Arbor. “This is the first time [TPVs have] gotten into really promising efficiency ranges, which is ultimately what matters for a lot of applications.” Together with related advances, he and others say, the new work gives a major boost to efforts to roll out thermal batteries on a large scale, as cheap backup for renewable power systems.

The idea is to feed surplus wind or solar electricity to a heating element, which boosts the temperature of a liquid metal bath or a graphite block to several thousand degrees. The heat can be turned back into electricity by making steam that drives a turbine, but there are trade-offs. High temperatures raise the conversion efficiency, but turbine materials begin to break down at about 1500°C. TPVs offer an alternative: Funnel the stored heat to a metal film or filament, setting it aglow like the tungsten wire in an incandescent light bulb, then use TPVs to absorb the emitted light and turn it to electricity.

Top of Form

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When the first TPVs were invented in the 1960s, they only converted a few percent of the heat energy into electricity. That efficiency jumped to about 30% in 1980, where it has largely been stuck ever since. One reason is that tungsten and other metals tend to radiate photons across a broad spectrum, from high-energy ultraviolet to low-energy far-infrared. But all photovoltaics—TPVs included—are optimized to absorb photons in a narrow range, meaning light with higher and lower frequencies tends to be wasted.

For the new device, Asegun Henry, an MIT mechanical engineer, tinkered with both the emitter and the TPV itself. Previous TPV setups heated the emitters to about 1400°C, which maximized their brightness in the wavelength range for which TPVs were optimized. Henry aimed to push the temperature 1000°C higher, where tungsten emits more photons at higher energies, which could improve the energy conversion. But that meant reworking the TPVs as well.

With researchers at the National Renewable Energy Laboratory, Henry’s team laid down more than two dozen thin layers of different semiconductors to create two separate cells stacked one on top of another. The top cell absorbs mostly visible and ultraviolet photons, whereas the lower cell absorbs mostly infrared. A thin gold sheet under the bottom cell reflects low-energy photons the TPVs couldn’t harvest. The tungsten reabsorbs that energy, preventing it from being lost. The result, the group reports today in Nature, [is a TPV tandem that converts 41.1% of the energy emitted](https://www.nature.com/articles/s41586-022-04473-y) from a 2400°C tungsten filament to electricity.

#### ADVERTISEMENT

Henry’s team sees ways to do even better. In the 8 October 2020 issue of Nature, Lenert and his colleagues reported [a mirror able to reflect nearly 99% of unabsorbed infrared photons back into the heat source](https://www.nature.com/articles/s41586-020-2717-7). Coupling the mirror with the MIT group’s improved TPVs could yield another big boost. “We think we have a clear path to 50% efficiency,” Henry says.

The TPVs are made from III-V semiconductors, named for where their component elements fall in the periodic table, which are more expensive than the silicon used in rooftop solar cells. But other parts of a thermal battery, including graphite, are cheap. [In a 2019 paper](https://pubs.rsc.org/en/content/articlelanding/2019/ee/c8ee02341g), Henry and his colleagues had calculated that even a 35% efficiency in heat-to-electricity conversion would make the technology economically viable. The team has also created ceramic pumps that can handle the ultra–high-temperature liquid metals needed to carry heat around an industrial scale heat energy storage setup. “They’ve built a foundation for storing and converting heat at those high temperatures,” Lenert says.

This progress has triggered commercial interest. Antora Energy in California launched a thermal energy company in 2016. Lenert and others are eyeing their own startups. And Henry recently launched a venture—Thermal Battery Corp.—to commercialize his group’s technology, which he estimates could store electricity for $10 per kilowatt-hour of capacity, less than one-tenth the cost of grid-scale lithium-ion batteries. “Storing energy as heat can be very cheap,” even for many days at a time, says Alina LaPotin, an MIT graduate student and first author of the current Nature paper.

Henry and others add that thermal storage systems are modular, unlike fossil fuel plants, which are most efficient at a massive, gigawatt scale. “That makes them equally good at providing power for a small village or a large power plant,” says Alejandro Datas, an electrical engineer at the Polytechnic University of Madrid—and for storing power from solar and wind farms of any size. “This is the beauty.”

# A new concept for batteries made from inexpensive, abundant materials

## Low-cost backup storage for renewable energy sources

DAVID L. CHANDLER    ·    JANUARY 25, 2023    ·    [MIT NEWS](https://news.mit.edu/2022/aluminum-sulfur-battery-0824)

The three primary constituents of the battery are aluminum (left), sulfur (center), and rock salt crystals (right). All are domestically available Earth-abundant materials not requiring a global supply chain. Credit: Rebecca Miller

As the world builds out ever larger installations of wind and solar power systems, the need is growing fast for economical, large-scale backup systems to provide power when the sun is down and the air is calm. Today’s lithium-ion batteries are still too expensive for most such applications, and other options such as pumped hydro require specific topography that’s not always available.

Now, researchers at MIT and elsewhere have developed a new kind of battery, made entirely from abundant and inexpensive materials, that could help to fill that gap.

The new battery architecture, which uses aluminum and sulfur as its two electrode materials, with a molten salt electrolyte in between, is described in the journal Nature in a [paper](https://doi.org/10.1038/s41586-022-04983-9) by MIT Professor [Donald Sadoway](https://energy.mit.edu/profile/donald-sadoway/), along with 15 others at MIT and in China, Canada, Kentucky, and Tennessee.

“I wanted to invent something that was better, much better, than lithium-ion batteries for small-scale stationary storage, and ultimately for automotive [uses],” explains Sadoway, who is the John F. Elliott Professor Emeritus of Materials Chemistry.

In addition to being expensive, lithium-ion batteries contain a flammable electrolyte, making them less than ideal for transportation. So, Sadoway started studying the periodic table, looking for cheap, Earth-abundant metals that might be able to substitute for lithium. The commercially dominant metal, iron, doesn’t have the right electrochemical properties for an efficient battery, he says. But the second-most-abundant metal in the marketplace—and actually the most abundant metal on Earth—is aluminum. “So, I said, well, let’s just make that a bookend. It’s gonna be aluminum,” he says.

Then came deciding what to pair the aluminum with for the other electrode, and what kind of electrolyte to put in between to carry ions back and forth during charging and discharging. The cheapest of all the non-metals is sulfur, so that became the second electrode material. As for the electrolyte, “we were not going to use the volatile, flammable organic liquids” that have sometimes led to dangerous fires in cars and other applications of lithium-ion batteries, Sadoway says. They tried some polymers but ended up looking at a variety of molten salts that have relatively low melting points—close to the boiling point of water, as opposed to nearly 1,000 degrees Fahrenheit for many salts. “Once you get down to near body temperature, it becomes practical” to make batteries that don’t require special insulation and anti-corrosion measures, he says.

The three ingredients they ended up with are cheap and readily available—aluminum, no different from the foil at the supermarket; sulfur, which is often a waste product from processes such as petroleum refining; and widely available salts. “The ingredients are cheap, and the thing is safe—it cannot burn,” Sadoway says.

In their experiments, the team showed that the battery cells could endure hundreds of cycles at exceptionally high charging rates, with a projected cost per cell of about one-sixth that of comparable lithium-ion cells. They showed that the charging rate was highly dependent on the working temperature, with 110 degrees Celsius (230 degrees Fahrenheit) showing 25 times faster rates than 25°C (77°F).

Surprisingly, the molten salt the team chose as an electrolyte simply because of its low melting point turned out to have a fortuitous advantage. One of the biggest problems in battery reliability is the formation of dendrites, which are narrow spikes of metal that build up on one electrode and eventually grow across to contact the other electrode, causing a short-circuit and hampering efficiency. But this particular salt, it happens, is very good at preventing that malfunction.

The chloro-aluminate salt they chose “essentially retired these runaway dendrites, while also allowing for very rapid charging,” Sadoway says. “We did experiments at very high charging rates, charging in less than a minute, and we never lost cells due to dendrite shorting.”

“It’s funny,” he says, because the whole focus was on finding a salt with the lowest melting point, but the catenated chloro-aluminates they ended up with turned out to be resistant to the shorting problem. “If we had started off with trying to prevent dendritic shorting, I’m not sure I would’ve known how to pursue that,” Sadoway says. “I guess it was serendipity for us.”

What’s more, the battery requires no external heat source to maintain its operating temperature. The heat is naturally produced electrochemically by the charging and discharging of the battery. “As you charge, you generate heat, and that keeps the salt from freezing. And then, when you discharge, it also generates heat,” Sadoway says. In a typical installation used for load-leveling at a solar generation facility, for example, “you’d store electricity when the sun is shining, and then you’d draw electricity after dark, and you’d do this every day. And that charge-idle-discharge-idle is enough to generate enough heat to keep the thing at temperature.”

This new battery formulation, he says, would be ideal for installations of about the size needed to power a single home or small to medium business, producing on the order of a few tens of kilowatt-hours of storage capacity.

For larger installations, up to utility scale of tens to hundreds of megawatt-hours, other technologies might be more effective, including the liquid-metal batteries Sadoway and his students developed several years ago and which formed the basis for a spinoff company called Ambri, which hopes to deliver its first products within the next year. For that invention, Sadoway was recently awarded this year’s European Inventor Award.

The smaller scale of the aluminum-sulfur batteries would also make them practical for uses such as electric vehicle charging stations, Sadoway says. He points out that when electric vehicles become common enough on the roads that several cars want to charge up at once, as happens today with gasoline fuel pumps, “if you try to do that with batteries and you want rapid charging, the amperages are just so high that we don’t have that amount of amperage in the line that feeds the facility.” So having a battery system such as this to store power and then release it quickly when needed could eliminate the need for installing expensive new power lines to serve these chargers.

The new technology is already the basis for a new spinoff company called Avanti, which has licensed the patents to the system, co-founded by Sadoway and Luis Ortiz ’96, ScD ’00, who was also a co-founder of Ambri. “The first order of business for the company is to demonstrate that it works at scale,” Sadoway says, and then subject it to a series of stress tests, including running through hundreds of charging cycles.

Would a battery based on sulfur run the risk of producing the foul odors associated with some forms of sulfur? Not a chance, Sadoway says. “The rotten-egg smell is in the gas, hydrogen sulfide. This is elemental sulfur, and it’s going to be enclosed inside the cells.” If you were to try to open up a lithium-ion cell in your kitchen, he says (and please don’t try this at home!), “the moisture in the air would react and you’d start generating all sorts of foul gases as well. These are legitimate questions, but the battery is sealed, it’s not an open vessel. So I wouldn’t be concerned about that.”

The research team included members from Peking University, Yunnan University, and the Wuhan University of Technology, in China; the University of Louisville, in Kentucky; the University of Waterloo, in Canada; Argonne National Laboratory, in Illinois; and MIT. The work was supported by the MIT Energy Initiative, the MIT Deshpande Center for Technological Innovation, and ENN Group.

# “Sun in a box” would store renewable energy for the grid

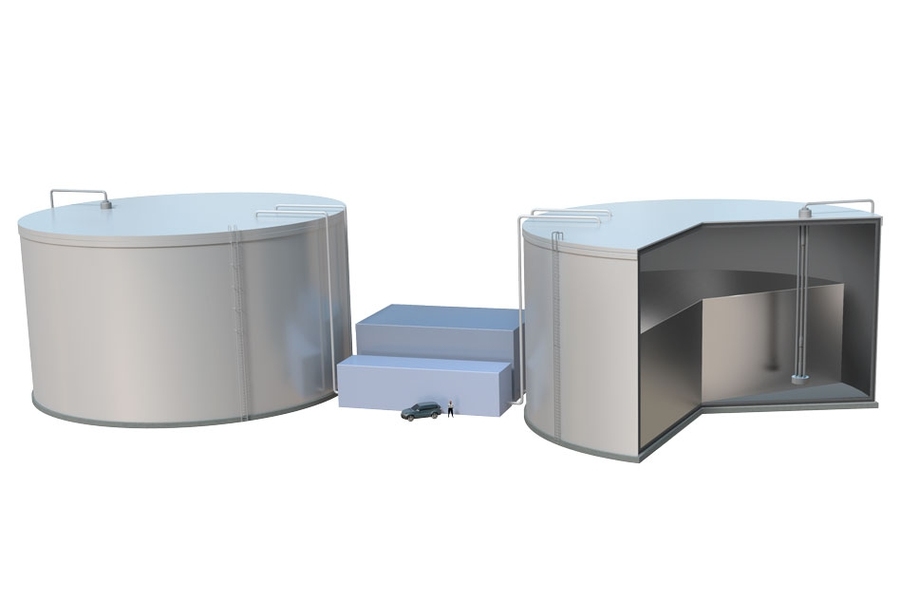
**Design for system that provides solar- or wind-generated power on demand should be cheaper than other leading options.**

**Jennifer Chu**|**MIT News Office**

**Publication Date:**

**December 5, 2018**

[**PRESS INQUIRIES**](https://news.mit.edu/2018/liquid-silicon-store-renewable-energy-1206#press-inquiries)



Caption:

MIT researchers propose a concept for a renewable storage system, pictured here, that would store solar and wind energy in the form of white-hot liquid silicon, stored in heavily insulated tanks.

Credits:

Image: Duncan MacGruer

MIT engineers have come up with a conceptual design for a system to store renewable energy, such as solar and wind power, and deliver that energy back into an electric grid on demand. The system may be designed to power a small city not just when the sun is up or the wind is high, but around the clock.

The new design stores heat generated by excess electricity from solar or wind power in large tanks of white-hot molten silicon, and then converts the light from the glowing metal back into electricity when it’s needed. The researchers estimate that such a system would be vastly more affordable than lithium-ion batteries, which have been proposed as a viable, though expensive, method to store renewable energy. They also estimate that the system would cost about half as much as pumped hydroelectric storage — the cheapest form of grid-scale energy storage to date.

“Even if we wanted to run the grid on renewables right now we couldn’t, because you’d need fossil-fueled turbines to make up for the fact that the renewable supply cannot be dispatched on demand,” says Asegun Henry, the Robert N. Noyce Career Development Associate Professor in the Department of Mechanical Engineering. “We’re developing a new technology that, if successful, would solve this most important and critical problem in energy and climate change, namely, the storage problem.”

Henry and his colleagues have published their design today in the journal Energy and Environmental Science.

**Record temps**

The new storage system stems from a project in which the researchers looked for ways to increase the efficiency of a form of renewable energy known as concentrated solar power. Unlike conventional solar plants that use solar panels to convert light directly into electricity, concentrated solar power requires vast fields of huge mirrors that concentrate sunlight onto a central tower, where the light is converted into heat that is eventually turned into electricity.

“The reason that technology is interesting is, once you do this process of focusing the light to get heat, you can store heat much more cheaply than you can store electricity,” Henry notes.

Concentrated solar plants store solar heat in large tanks filled with molten salt, which is heated to high temperatures of about 1,000 degrees Fahrenheit. When electricity is needed, the hot salt is pumped through a heat exchanger, which transfers the salt’s heat into steam. A turbine then turns that steam into electricity.

“This technology has been around for a while, but the thinking has been that its cost will never get low enough to compete with natural gas,” Henry says. “So there was a push to operate at much higher temperatures, so you could use a more efficient heat engine and get the cost down.”

However, if operators were to heat the salt much beyond current temperatures, the salt would corrode the stainless steel tanks in which it’s stored. So Henry’s team looked for a medium other than salt that might store heat at much higher temperatures. They initially proposed a liquid metal and eventually settled on silicon — the most abundant metal on Earth, which can withstand incredibly high temperatures of over 4,000 degrees Fahrenheit.

Last year, the team developed a pump that could withstand such blistering heat, and could conceivably pump liquid silicon through a renewable storage system. The pump has the highest heat tolerance on record — a feat that is noted in “The Guiness Book of World Records.” Since that development, the team has been designing an energy storage system that could incorporate such a high-temperature pump.

**“Sun in a box”**

Now, the researchers have outlined their concept for a new renewable energy storage system, which they call TEGS-MPV, for Thermal Energy Grid Storage-Multi-Junction Photovoltaics. Instead of using fields of mirrors and a central tower to concentrate heat, they propose converting electricity generated by any renewable source, such as sunlight or wind, into thermal energy, via joule heating — a process by which an electric current passes through a heating element.

The system could be paired with existing renewable energy systems, such as solar cells, to capture excess electricity during the day and store it for later use. Consider, for instance, a small town in Arizona that gets a portion of its electricity from a solar plant.

“Say everybody’s going home from work, turning on their air conditioners, and the sun is going down, but it’s still hot,” Henry says. “At that point, the photovoltaics are not going to have much output, so you’d have to have stored some of the energy from earlier in the day, like when the sun was at noon. That excess electricity could be routed to the storage system we’ve invented here.”

The system would consist of a large, heavily insulated, 10-meter-wide tank made from graphite and filled with liquid silicon, kept at a “cold” temperature of almost 3,500 degrees Fahrenheit. A bank of tubes, exposed to heating elements, then connects this cold tank to a second, “hot” tank. When electricity from the town’s solar cells comes into the system, this energy is converted to heat in the heating elements. Meanwhile, liquid silicon is pumped out of the cold tank and further heats up as it passes through the bank of tubes exposed to the heating elements, and into the hot tank, where the thermal energy is now stored at a much higher temperature of about 4,300 F.

When electricity is needed, say, after the sun has set, the hot liquid silicon — so hot that it’s glowing white — is pumped through an array of tubes that emit that light. Specialized solar cells, known as multijunction photovoltaics, then turn that light into electricity, which can be supplied to the town’s grid. The now-cooled silicon can be pumped back into the cold tank until the next round of storage — acting effectively as a large rechargeable battery.

“One of the affectionate names people have started calling our concept, is ‘sun in a box,’ which was coined by my colleague Shannon Yee at Georgia Tech,” Henry says.  “It’s basically an extremely intense light source that’s all contained in a box that traps the heat.”

**A storage key**

Henry says the system would require tanks thick and strong enough to insulate the molten liquid within.

“The stuff is glowing white hot on the inside, but what you touch on the outside should be room temperature,” Henry says.

He has proposed that the tanks be made out of graphite. But there are concerns that silicon, at such high temperatures, would react with graphite to produce silicon carbide, which could corrode the tank.

To test this possibility, the team fabricated a miniature graphite tank and filled it with liquid silicon. When the liquid was kept at 3,600 F for about 60 minutes, silicon carbide did form, but instead of corroding the tank, it created a thin, protective liner.

“It sticks to the graphite and forms a protective layer, preventing further reaction,” Henry says. “So you can build this tank out of graphite and it won’t get corroded by the silicon.”

The group also found a way around another challenge: As the system’s tanks would have to be very large, it would be impossible to build them from a single piece of graphite. If they were instead made from multiple pieces, these would have to be sealed in such a way to prevent the molten liquid from leaking out. In their paper, the researchers demonstrated that they could prevent any leaks by screwing pieces of graphite together with carbon fiber bolts and sealing them with grafoil — flexible graphite that acts as a high-temperature sealant.

The researchers estimate that a single storage system could enable a small city of about 100,000 homes to be powered entirely by renewable energy.

“Innovation in energy storage is having a moment right now,” says Addison Stark, associate director for energy innovation at the Bipartisan Policy Center, and staff director for the American Energy Innovation Council. “Energy technologists recognize the imperative to have low-cost, high-efficiency storage options available to balance out nondispatchable generation technologies on the grid. As such, there are many great ideas coming to the fore right now. In this case, the development of a solid-state power block coupled with incredibly high storage temperatures pushes the boundaries of what’s possible.”

Henry emphasizes that the system’s design is geographically unlimited, meaning that it can be sited anywhere, regardless of a location’s landscape. This is in contrast to pumped hydroelectric — currently the cheapest form of energy storage, which requires locations that can accommodate large waterfalls and dams, in order to store energy from falling water.

“This is geographically unlimited, and is cheaper than pumped hydro, which is very exciting,” Henry says. “In theory, this is the linchpin to enabling renewable energy to power the entire grid.”