Solar energy, radiant [light](http://en.wikipedia.org/wiki/Light) and [heat](http://en.wikipedia.org/wiki/Heat) from the [sun](http://en.wikipedia.org/wiki/Sun), has been harnessed by humans since [ancient times](http://en.wikipedia.org/wiki/Ancient_history) using a range of ever-evolving technologies. Solar energy technologies include [solar heating](http://en.wikipedia.org/wiki/Solar_heating), [solar photovoltaic](http://en.wikipedia.org/wiki/Solar_photovoltaics), [solar thermal electricity](http://en.wikipedia.org/wiki/Solar_thermal_electricity) and [solar architecture](http://en.wikipedia.org/wiki/Solar_architecture), which can make considerable contributions to solving some of the most urgent problems the world now faces.



Solar power is the conversion of sunlight into [electricity](http://en.wikipedia.org/wiki/Electricity), either directly using [photovoltaic](http://en.wikipedia.org/wiki/Photovoltaics) (PV), or indirectly using [concentrated solar power](http://en.wikipedia.org/wiki/Concentrated_solar_power) (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric.

One of the drawbacks of [solar energy](http://www.solar-energy-at-home.com/what-is-solar-energy.html) systems is that the Sun doesn't provide a constant stream of energy. On cloudy days or at night, the amount of energy your system receives is reduced or eliminated altogether. This in turn impacts the amount of electricity or heat that your system produces during those times.

To overcome this drawback, homeowners can take advantage of several methods available to them for storing solar energy. The methods available differ depending on whether you are using [solar electricity](http://www.solar-energy-at-home.com/solar-electricity.html) applications or [solar heating](http://www.solar-energy-at-home.com/solar-heating.html) applications.

Solar Electricity Storage

Homeowners are able to generate solar electricity by using a [photovoltaic solar power](http://www.solar-energy-at-home.com/photovoltaic-solar-power.html)system. There are two primary methods of [Energy Storage](http://www.amazon.com/gp/product/0470625910/ref%3Das_li_ss_tl?ie=UTF8&tag=soenatho-20&linkCode=as2&camp=217145&creative=399373&creativeASIN=0470625910) with a PV solar powersystem...

* Battery Banks
* Grid Inter-Tie

One way solar power storage can be accomplished is by using a battery bank to store the electricity generated by the PV solar power system. A battery solar power storage system is used in a [grid-tied PV system with battery backup](http://www.solar-energy-at-home.com/solar-electricity.html#battery) and [stand-alone PV systems](http://www.solar-energy-at-home.com/solar-electricity.html#standalone).

The major components of a battery solar power system are...

* Charge Controller: Prevents the battery bank from overcharging by interrupting the flow of electricity from the PV panels when the battery bank is full.
* Battery Bank: A group of batteries wired together. The batteries are similar to car batteries, but designed specifically to endure the type of charging and discharging they'll need to handle in a solar power system.
* System Meter: Measures and displays your solar PV systems performance and status.
* Main DC Disconnect: A DC rated breaker between the batteries and the inverter. Allows the inverter to be quickly disconnected from the battery bank for service.

The third type of PV solar power system is a [grid-tied PV system](http://www.solar-energy-at-home.com/solar-electricity.html#gridtied). This system can actually use the grid as its solar energy storage system. This is done using [net-metering](http://www.solar-energy-at-home.com/net-metering.html).

With net-metering, when you produce excess solar electricity, you send it to the grid and your electric meter rolls backwards. Later on, at night for example, when your system is not producing electricity, you can pull electricity from the grid and your electric meter will roll forward. You are essentially using the grid to store your solar electricity!

Solar Thermal Storage

There are three solar heating applications...

* Solar Space Heating
* Solar Water Heating
* Solar Pool Heating

Each of these solar heating applications uses their own methods for [Solar Thermal Energy Storage](http://www.amazon.com/gp/product/9027719306/ref%3Das_li_ss_tl?ie=UTF8&tag=soenatho-20&linkCode=as2&camp=217145&creative=399373&creativeASIN=9027719306).

Thermal mass and water tanks are the two primary methods of storing solar energy in[solar space heating](http://www.solar-energy-at-home.com/solar-space-heating.html) systems.

* Thermal Mass: Used in both passive and active space heating systems. Absorbs heat during the day and slowly releases it at night.
* Water Tanks: Used in active liquid systems. A heat-exchanger transfers the heat from the heat-transfer fluid to the water in the tank.

[Solar water heating](http://www.solar-energy-at-home.com/solar-water-heating.html) systems use water tanks for the storage of solar energy. Both passive and active solar water heating use water tanks. Active indirect systems use a heat-exchanger to transfer the heat from the heat-transfer fluid. The other solar water heating systems use the actual household water and therefore do not need a water tank with a heat-exchanger.

[Solar pool heating](http://www.solar-energy-at-home.com/solar-pool-heating.html) uses the swimming pool water for solar energy storage. By circulating your swimming pool water through solar pool collectors, you will be able to extend your swimming season.

Solar Energy Storage for Homeowners

So, how is solar energy stored in residential solar energy systems?

For solar electricity, it is stored using either batteries or the grid.

For solar heating, it is stored using thermal mass, water tanks, or swimming pool water.

Stored at night

## How to Use Solar Energy at Night

Molten salts can store the sun's heat during the day and provide power at night





SUNSHINE STORAGE IN A SALT: The molten salts stored in the two tanks pictured here amidst the rows of troughs at the Andasol 1 power plant in Spain will allow solar energy to produce electricity even at night.Image: COURTESY OF SOLAR MILLENNIUM

### Supplemental Material

* [OverviewCan Geothermal Power in Iceland Thaw a Frozen Economy?](http://www.sciam.com/article.cfm?id=iceland-geothermal-to-thaw-frozen-economy)
* [OverviewMan-Made Geothermal Power: Wresting Energy from Hot Rocks--One Kilowatt at a Time [Slide Show]](http://www.sciam.com/article.cfm?id=man-made-geothermal-power)

Near Granada, Spain, more than 28,000 metric tons of salt is now coursing through pipes at the [Andasol 1](http://www.solarmillennium.de/Technologie/Referenzprojekte/Andasol/Die_Andasol_Kraftwerke_entstehen_%2Clang2%2C109%2C155.html) power plant. That salt will be used to solve a pressing if obvious problem for [solar power](http://www.scientificamerican.com/topic.cfm?id=solar-power): What do you do when the sun is not shining and at night?

The answer: store sunlight as heat energy for such a rainy day.

Part of a so-called parabolic trough [solar-thermal power plant](http://www.sciam.com/article.cfm?id=sunny-outlook-sunshine-provide-electricity), the salts will soon help the facility light up the night—literally. Because most salts only melt at high temperatures (table salt, for example, melts at around 1472 degrees Fahrenheit, or 800 degrees Celsius) and do not turn to vapor until they get considerably hotter—they can be used to store a lot of the sun's energy as heat. Simply use the sunlight to heat up the salts and put those molten salts in proximity to [water](http://www.scientificamerican.com/topic.cfm?id=water) via a heat exchanger. Hot steam can then be made to turn turbines without losing too much of the original absorbed solar energy.

The salts—a mixture of sodium and potassium nitrate, otherwise used as fertilizers—allow enough of the sun's heat to be stored that the power plant can pump out electricity for nearly eight hours after the sun starts to set. "It's enough for 7.5 hours to produce energy with full capacity of 50 megawatts," says Sven Moormann, a spokesman for [Solar Millennium, AG](http://www.solarmillennium.de/index%2Ccat1.html), the German solar company that developed the Andasol plant. "The hours of production are nearly double [those of a solar-thermal] power plant without storage and we have the possibility to plan our electricity production."

**Using mirrors to concentrate the sun's energy** is an old trick—the ancient Chinese and Greeks both used it to start fires—and modern power [plants](http://www.scientificamerican.com/topic.cfm?id=plants) employing it might provide a significant source of renewable energy without any [greenhouse gas emissions](http://www.sciam.com/article.cfm?id=from-bad-to-worse-with-greenhouse-gas-emissions).

That is a step forward in its own right, but such power plants are limited to generating energy only when there is sunshine. So engineers have tried a number of different technologies to store the sun's energy so that such power plants can be more broadly employed. They have tried [batteries](http://www.sciam.com/article.cfm?id=storing-the-breeze-new-battery-might-make-wind-power-reliable) but too much of the energy that goes in is not returned, and they tend to be too expensive, according to an analysis from the[National Renewable Energy Laboratory](http://www.nrel.gov/) (NREL) in Golden, Colo. Compressing air or pumping water uphill are more promising, but the opportunities to do that are limited by the number of caverns and the availability of water and reservoirs.

Melting salts at temperatures above 435 degrees Fahrenheit (224 degrees Celsius), however, can deliver back as much as 93 percent of the energy, plus the salts are ubiquitous because of their application as [fertilizers](http://www.sciam.com/article.cfm?id=new-nonexplosive-fertilizer).

"There's a term called round-trip efficiency. Basically, it's a measure of how much electricity is produced if the thermal energy that's generated is first stored and then used compared to just directly taking the energy. That number is around 93 percent," explains [NREL](http://www.nrel.gov/csp/) senior engineer Greg Glatzmaier. "[For] things like compressed air and mechanical type storage, there's more significant losses," an average of at least 20 percent over all the various technologies.

The Andasol 1 power plant, which cost around $380 million (300 million euros) to build, is the first to actually use the technology, so it remains to be seen how it will work in commercial practice. But U.S. government laboratories—NREL as well as[Sandia National Laboratory](http://energylan.sandia.gov/sunlab/) in Albuquerque, N.M.—have already proved the technology can work in demonstration projects that employed it, like the Solar Two power tower outside Barstow, Calif.

Solar Millennium is so confident the technology will work that a twin [solar-thermal power plant](http://www.sciam.com/article.cfm?id=sunny-outlook-sunshine-provide-electricity) (Andasol 2) is already near completion. "It will start operations at the beginning of summer—May or June," Moormann says.

And [Arizona Public Service Co.](http://www.aps.com/) (APS) has contracted with Abengoa Solar to build a 280-megawatt solar thermal power plant—dubbed [Solana](http://www.aps.com/solana) or "sunny place"—70 miles (110 kilometers) southwest of Phoenix on nearly 2,000 acres (800 hectares) of land. "One of the great things about molten salt technology is that you can get more out of the pure solar resources, more energy out of the same facility," says Barbara Lockwood, manager for renewable energy at APS. "It's an alternative that provides us with additional green energy," as much as 1,680 megawatt-hours when cloudy or after sunset.

But that extra energy comes at a cost. First, the power plant has to be enlarged so that it is both generating its full electrical capacity as well as heating up the salts. In the case of Andasol 1 that meant covering 126 acres (50 hectares) with long rows of troughs and pipe. And then there is the additional expense of the molten salt storage tanks, according to Moormann.

All told, that means thermal energy storage at Andasol 1 or power plants like it costs roughly $50 per kilowatt-hour to install, according to NREL's Glatzmaier. But it doesn't add much to the cost of the resulting electricity because it allows the turbines to be generating for longer periods and those costs can be spread out over more hours of electricity production. Electricity from a [solar-thermal power plant](http://www.sciam.com/article.cfm?id=sunny-outlook-sunshine-provide-electricity) costs roughly 13 cents a kilowatt-hour, according to Glatzmaier, both with and without molten salt storage systems.

That price is still nearly twice as much as electricity from a [coal-fired power plant](http://www.sciam.com/blog/60-second-science/post.cfm?id=coal-war-can-the-fossil-fuel-be-cle-2008-12-23)—the current cheapest generation option if environmental costs are not taken into account. But Arizona's APS and others can then use solar energy to meet the maximum electricity demand later in the day. "Our peak demand [for electricity] is later in the evening, once solar production is trailing off," Lockwood says. That's "the reason we went that direction and are so interested in storage technology."

**As efficient as** [solar-thermal power plants](http://www.sciam.com/article.cfm?id=sunny-outlook-sunshine-provide-electricity) using parabolic troughs with molten salt storage systems like Andasol 1 or Solana are, they don’t capture as much of the sun's heat as is possible. Above 750 degrees F (400 degrees C), the synthetic oils used to capture the sun’s heat in the troughs begin to break down, but the molten salts can take in much more heat than that.

To allow the salts to get hotter, some companies, such as [SolarReserve](http://www.solar-reserve.com/) in Santa Monica, Calif., are developing so-called [power towers](http://www.sciam.com/article.cfm?id=is-the-sun-setting-on-solar-power-in-spain)—vast fields of mirrors that concentrate sunlight onto a central tower. Because of the centralized design such a structure can operate at much higher temperatures—up to 1,000 degrees F (535 degrees C)—and use molten salts directly as the fluid transferring heat in the power plant. "We are heating the salts to more than 1,000 degrees F and that results in the same inlet conditions that utilities see today on a coal-fired or [nuclear power](http://www.scientificamerican.com/topic.cfm?id=nuclear-power) plant," says Terry Murphy, SolarReserve's president.

But such a power plant—and Murphy says the company has some 50 such projects in the pipeline and expects at least one (in the U.S. or Spain) to be operating by 2013—would cost as much as $800 million for a 200-megawatt [power tower](http://www.sciam.com/article.cfm?id=is-the-sun-setting-on-solar-power-in-spain). "The first molten salt power tower built is going to be a real trial," says Thomas Mancini, manager of Sandia's [Concentrating Solar Power Program](http://www.sandia.gov/Renewable_Energy/solarthermal/NSTTF/salt.htm). "It's going to take someone progressive enough to finance it or take a little more risk."

So researchers are also looking into salts that could be used instead of the oil in parabolic trough power plants, such as those that melt at lower temperatures and therefore would not freeze as readily during cold nights, according to Hank Price, a vice president for technology development at [Abengoa Solar](http://www.abengoasolar.com/sites/solar/en/).

Solar Millennium is working on such a salt, according to Moormann, and Sandia has developed small quantities of a new mixture of salts, including calcium nitrate and lithium nitrate, that melt below 212 degrees F (100 degrees C). "With the lithium nitrate, it's as expensive as all the other constituents combined. Though still a lot cheaper than organic heat-transfer oils," says chemical engineer Bob Bradshaw at Sandia in California, who is leading the research. "You don't get something for nothing."

And long-term research projects are looking at other thermal storage technologies, such as storing heat in sand or creating single-tank molten salt storage. "The main goal is to find a storage technology that may reduce the actual capital cost" of adding it to a power plant, says Phil Smithers, technical services leader for renewable energy at APS, which is researching those technologies under a [U.S. Department of Energy grant](http://www.aps.com/main/news/releases/release_490.html).

Ultimately, it will come down to how much value policymakers and consumers put on electricity that is renewable and emissions-free. "If we start valuing carbon and force a coal plant to go [carbon-free via sequestration](http://www.sciam.com/article.cfm?id=future-of-clean-coal-tied-to-success-of-carbon-capture-and-storage) then we're at or over 10 cents per kilowatt-hour from coal," Mancini says. "Any of these technologies can get to that same 10 cents level with [molten salt] storage. Then the market will make the call."

And should Andasol 1 spring a leak or otherwise fail to deliver as expected, the damage would not be confined to a pile of salt fertilizer on the ground—it could be a setback for the entire effort to store [solar energy](http://www.sciam.com/article.cfm?id=a-solar-grand-plan). "We had to build the first [commercial] plant [with molten salt storage] and that's what Andasol is," Mancini says, in order to prove the technology. "It doesn't have to be perfect, but they've got to make it work."