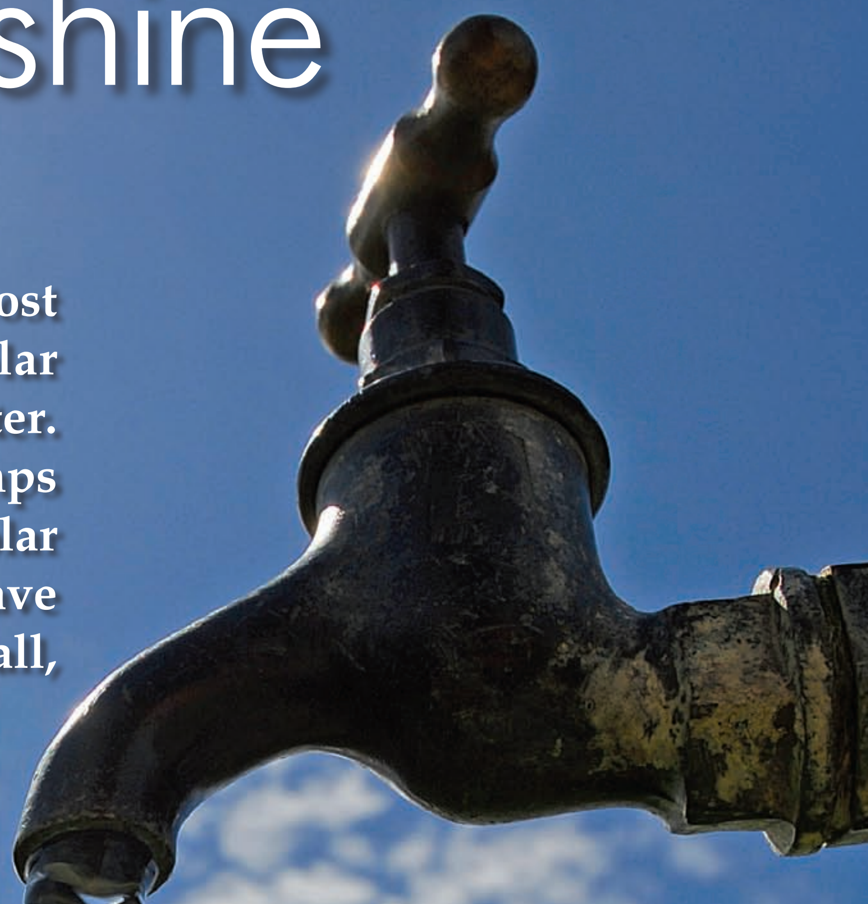
Pumping Water with Sunshine

by Erik Lensch



One of the simplest and most economical uses of solar energy is for pumping water. With advancements in pumps and pump controllers, solar water-pumping systems have become fairly easy to install, operate, and maintain.

If you live beyond the reach of the grid, or have a remote pumping need like irrigation or livestock watering, a solar-electric pump system can be a solution that's reliable and sustainable. This article covers the basics of several types of PV-powered pumping systems, including array-direct, battery-based, and both pressure-tank and high-volume water storage.

Solar Pump Types

There are two basic types of solar water pumps—submersible and surface. In this article, we'll be looking primarily at submersible pumps used to deliver potable water for domestic use. A submersible pump is usually positioned in a well, although there are instances where a stream or pond is used as the source. Unlike surface pumps (installed above the source's water level) that *draw* water up from shallow sources like a pond, submersible pumps *push* water up to a holding tank or pressure tank. The right-sized submersible can pump water out of deep wells, up to 1,000 feet or more. Most models are durable and can tolerate water with relatively high levels of silt.

Submersible pumps break down into three main categories—centrifugal, helical rotor, and diaphragm. **Centrifugal pumps** have an impeller that spins at high speeds, producing a high flow of water. Because the spinning rate is high, the flow rate is generally high. However, pressure, and therefore the amount of pumping height (head or lift) that can be attained, is usually lower than in other types of pumps.

Higher lift can be achieved with **helical rotor pumps** (a type of "positive displacement" pump), which will also provide a flow rate great enough to meet most household demands. With these pumps, picture the water being sent out of the pump body in small "packets" that are pumped very quickly to provide a constant flow. An analogy that is sometimes used is that of a spiral staircase in a sealed shaft, with the staircase spinning around very quickly. Each "stair step" lifts water toward the top of the pump, then to the pump outtake, and eventually out the top of the well. Since the water needs to be carried through the pump body, the result is a lower flow compared to centrifugal pumps. However, with its higher pressure, a helical rotor pump can deliver water against higher heads.

A pump controller like this SunPumps PCB-180BT balances PV voltage and current to optimize pump performance throughout the day.

Depending on the model, submersible **diaphragm pumps** (another type of positive displacement pump) can pump up to about 5 gpm from shallow wells (under 100 feet), or lower volumes from well depths down to approximately 250 feet. A 4-inch well casing is typically required. Although these pumps are less expensive than centrifugal or helical pumps, they require significantly more maintenance.

Different models of submersible pumps are designed to run on AC, DC, or both. To simplify wiring, off-grid residences with AC PV systems often rely on an AC submersible pump. It's important to note that most "AC" pumps actually utilize brushless DC motors. In this case, the pump contains electronics that allow it to be powered by a standard AC source like an inverter or the grid. The pump is just another AC load to be considered when sizing the system's battery bank, inverter, and charge sources. Many AC pumps will require two or more times the power (wattage) to start the pump than is needed when the pump is running, and the system's inverter needs to be able to handle this extra start-up load. The Grundfos SQ series of pumps is very popular in the off-grid world. These pumps have no start-up surge, and have a great reliability record in the field.

But DC submersibles take more efficient advantage of battery-based PV systems compared to AC pumps. AC pumping includes DC-to-AC conversion losses: A PV array's direct current is stored in batteries before being converted to AC by the system's inverter, which in turn, powers the pump. Inefficiencies associated with the charging and discharging of batteries can account for losses of 5% to 10% or more, depending on the age and condition of the battery pack. And with an inverter average conversion efficiency of approximately 85%, an AC pump will require approximately 20% to 25% more PV energy to pump the same amount of water compared to a DC-direct pump.

Submersible Pump Types

A DC submersible diaphragm pump (middle) and a centrifugal pump (right), with controller (left), by SunPumps.

A helical rotor pump (middle) and a centrifugal pump (right), with controller (left), by Lorentz.

Component Considerations

For either PV-direct or battery-based solar water pumping, the following design practices can ensure a top-notch system that maximizes your investment.

Site Right. For optimal performance, the array must be free of shading during the day and must be facing as close to true south as possible. For most residential water-pumping systems, the modules are set at a fixed tilt. But for applications that require a lot of water pumping during the summer, like irrigation, a sun-tracking PV module mount can maximize power production and pumping.

Trackers keep the modules perpendicular to the sun as it moves through the sky, providing more power to the pump over a longer period of the day. In the summertime, a tracked system with a clear horizon-to-horizon solar window can provide 20% to 40% more water than a fixed array.

Minimize Voltage Loss. To limit wiring voltage loss and minimize the length and the gauge of wire needed, locate the PV array as close to the pump or battery bank as possible. The greater the distance from the PV modules to the pump, the greater the voltage drop. Too much voltage loss can significantly reduce the amount of water pumped, and in some cases may be so great that the pump will not operate effectively.

Voltage loss should not exceed the accepted standard of 2%. For long distances, wire size must be increased, at additional expense. With the price of copper at an all-time high, it's usually cost-effective to locate the array as close to the pump or battery bank as possible. Your system designer can provide the wire-sizing calculation for you, or you can use software provided by the pump manufacturer.

Free Flow. Pipe friction is another important factor in optimizing pump production. The greater the distance between the pump's outtake and the delivery point, the greater the flow restriction from pipe friction. Much like voltage drop can be mitigated with larger wire size, flow restriction can be reduced by increasing the pipe size or reducing the distance. For household use, 1.25-inch- or 1.5-inch-diameter pipe is typical. However, if the distance exceeds 500 feet or the flow rate is expected to be unusually high, consider increasing the pipe diameter to 2 inches to keep friction losses down.

Pump Protection. To regulate flow, pressurized systems use a pressure switch. If a holding tank is used, a float or level switch turns off the pump when the water rises to a certain level. Some pumps require a "reverse-acting" pressure switch. Most pressure switches operate by closing the contacts when the pressure has risen to a preset point. Conversely, in a reverse-acting pressure switch, the contacts open when the pressure falls to a certain level.

Just as important is providing a shutoff mechanism for the pump. Damage can occur to the pump if it pumps against "shutoff" head when the holding tank is full and there's no overflow pipe or float switch in place. And to avoid damaging the pump if the water source runs dry, use dry-run protection (a water-level sensor) at the source. Some pumps have this built in, so check a given pump's specifications.

Under Control. All submersible water-pumping systems should have a controller between the power source and the pump. In PV-direct systems, the control can be as simple as using a linear current booster (LCB). An LCB optimizes array voltage and current, maximizing the volume of water pumped and helping the pump start sooner in low-light conditions. More advanced controllers include pump motor speed-control and low-water cutoff circuits. Some even provide information related to the system status, including how many watts the PV modules are producing, and can be helpful for system troubleshooting. Most pump manufacturers offer one or more controller options designed to be used with their pump model.

Arresting Lightning. Proper system grounding will usually protect the pump and control. But some manufacturer warranties also require a lightning arrestor be installed. As with any PV system, the array and its modules should be properly grounded. While a direct lightning strike will likely damage the controller, the pump may survive if the system is well-grounded.

Lorentz manufactures a range of pumps, some of which operate at up to 200 volts open circuit. Centrifugal DC pumps manufactured by SunPumps operate at up to 245 Voc. They offer models that can pump 4 gpm from wells up to 650 feet deep, or up to 250 gpm from shallow wells or surface water sources. SunPumps and Shurflo also make less expensive diaphragm pumps that can be good choices in array-direct (batteryless DC from PV modules) applications for domestic, irrigation, or livestock watering, provided that the water is relatively silt free.

Grundfos manufacturers the SQFlex, a centrifugal pump that can run on either AC or DC power—no special equipment is needed to make the switch. In DC systems, the pump only requires 30 VDC to get going, but the pump's 300-volt open-circuit limit allows the array to be wired at higher voltages, decreasing both wire size and cost. With the addition of a generator interface box, the pump can be switched to accept AC power from a generator during sunless periods.

A Lorentz PS150 Boost diaphragm surface pump is typically used to pressurize water systems.

Solar Pumping Systems

There are three general solar water-pumping system types. Your best solution will depend on elevation changes at your site, whether there are inverters in your system, and how much flexibility you have when it comes to *when* you pump water.

Array-Direct to Elevated Storage. The most efficient solar water-pumping systems are PV-direct without batteries. This classic off-grid pumping solution connects a DC submersible pump directly to the PV array. One additional component, either a controller or linear current booster (LCB) wired between the PV array and the pump, optimizes the relationship between array voltage and current to maximize the amount of water pumped under varying sunlight conditions. When the sun is shining, the pump moves water to a tank located above the water's point of use. (For potable water, use only drinking-water-grade tanks.) For each 2.31 feet of elevation, there will be 1 psi of water pressure. Many household water supplies operate at about 40 psi (though down to 20 psi can often work), so locating the storage tank about 100 feet higher than the point of use will provide adequate water pressure.

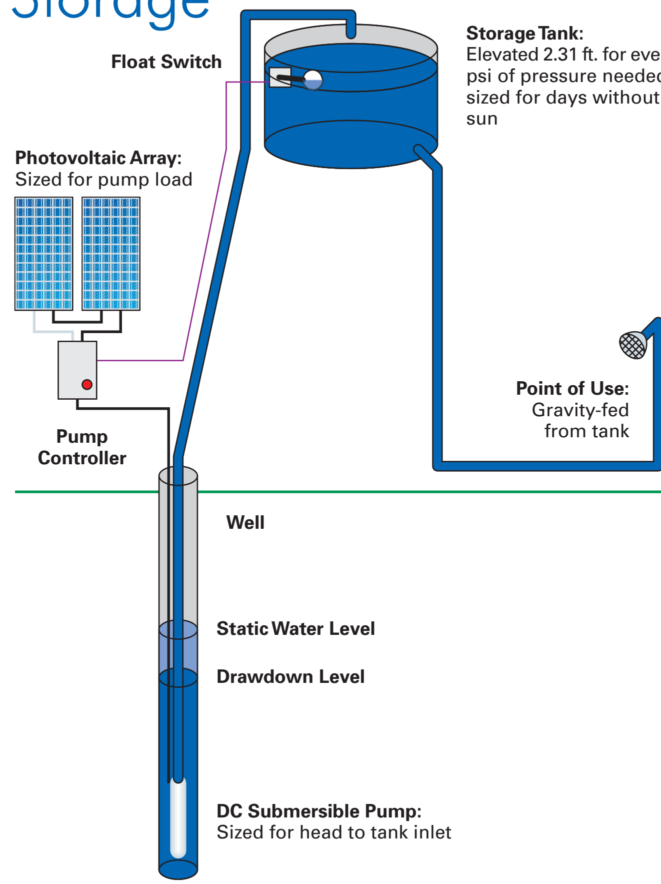
The beauty of these systems lies in their simplicity. The tank acts as a large "battery," storing the pumped water for later use. And since the elevation of the tank provides the needed water pressure, no pressurizing pumps or pressure tanks are required. For household domestic water systems, I recommend sizing the storage tank to hold at least five days' supply of water to cover those inevitable periods of cloudy weather. If properly sized, the pump will slowly fill the tank when the sun is shining. When the sun isn't shining, the pump doesn't run. It does not damage the pump to go on and off during the day as clouds pass over.

Other advantages of PV-direct pumping are the efficient use of PV energy (no losses to battery charging or inverter conversion) and the potential for reducing generator run-time. Off-grid system users often limit generator-based charging (and the associated noise, pollution, and fuel expense) by waiting to perform energy-intensive activities—like running the vacuum or shop tools—until there's plenty of solar energy available. This limits battery bank depth of discharge to extend battery life. In properly sized PV-direct to storage tank systems, several days' worth of water will be stored in the tank. During cloudy periods, you will already have pumped the water you need, and the generator won't be needed to keep the batteries topped off while pumping.

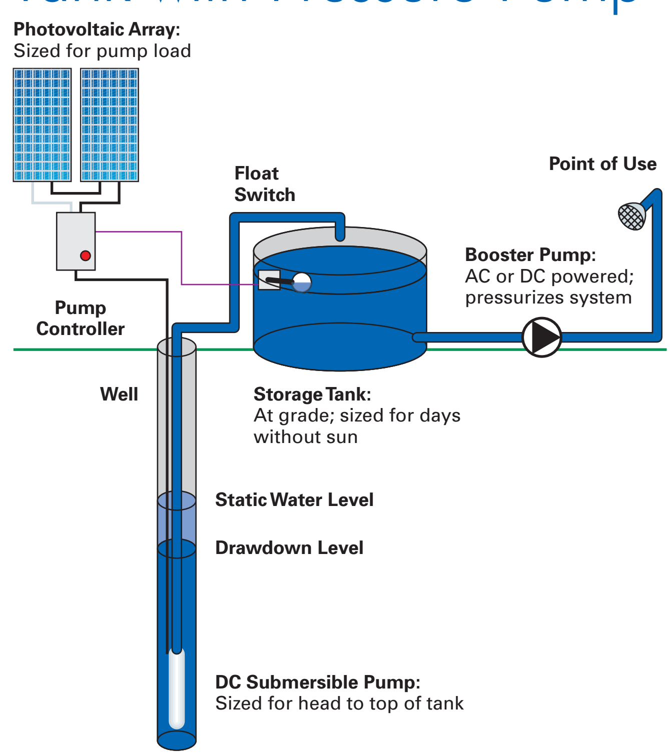
Array-direct to elevated storage systems will save you money in the long run and add more flexibility to your off-grid energy lifestyle. But keep in mind that the additional expense of the tank and for trenching the pipeline deep enough for freeze protection can make these systems more expensive up front than other options.

Array-Direct to Storage Tank with Pressure Pump. If you like the efficiency of DC pumping and want stored water at your disposal, but don't have enough of an elevation change on your property for a gravity system, there are still options.

Array-Direct to Elevated Storage



Array-Direct to Storage Tank with Pressure Pump



A PV-direct DC pump can be configured to fill a storage tank near its point of use, and an additional DC or AC booster pump can be installed at the tank to pressurize the water. This solution gets the heavy lifting (from the well to the storage tank) done whenever the sun's shining, and limits energy use during cloudy periods to a smaller pressure pump that activates via a pressure switch when water is used.

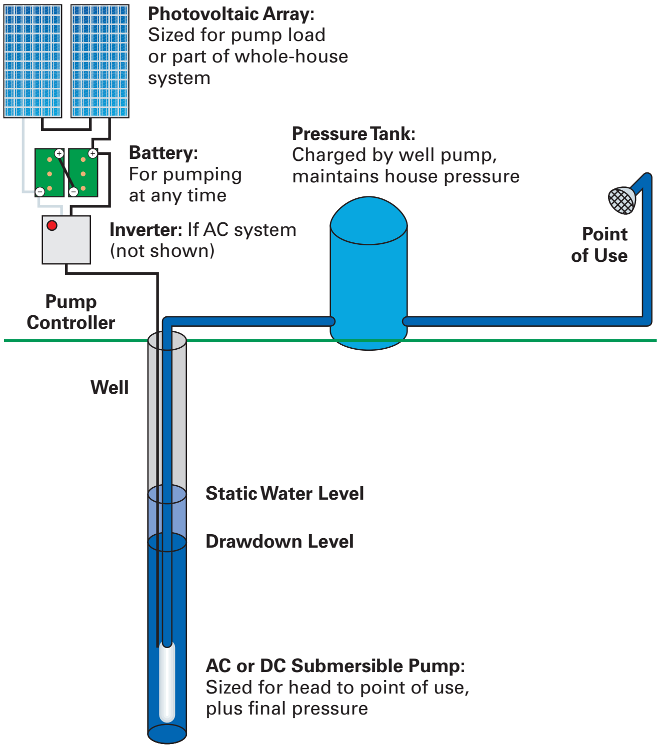
While this configuration gives you more flexibility to choose when you consume the energy required to pump well water, the up-front costs of the storage tank and additional pressure pump add to overall system cost and installation complexity.

Pump to Pressure Tank. The most conventional of the three pumping systems described uses an AC submersible pump to push water directly to a pressure tank. A DC pump sized to meet the site's flow rate requirements can also be run directly from the battery bank, eliminating inverter conversion losses. A standard pressure switch activates the pump when the pressure in the tank drops below a set level, say 30 psi. At 50 psi or so, the switch's upper-limit shuts off the pump. Instead of a 1,200-gallon or larger water storage tank, a smaller 40- to 60-gallon pressure tank is all that is needed.

Compared to the systems described earlier, pump-to-pressure tank systems usually have the lowest up-front component costs (there's no large storage tank or secondary booster pump), and pump installers everywhere are familiar with these systems. But they may not be familiar with the limitations of battery-based power sources (pump surge, inverter capacity issues, and the like), so pay close attention to the pump's operating characteristics and seek out an installer familiar with off-grid pumping systems whenever possible.

Installation of a Grundfos SQFlex submersible pump.

Pump to Pressure Tank



For off-grid installations, the downside of pump-to-pressure tank systems is that the pump will need to come on during most water draws. During cloudy weather or overnight, the energy to repressurize the tank will come from your battery bank. Batteries like to be fully charged, and the deeper you discharge them and the longer they stay in that state, the shorter their service life will be. Another consideration is that, compared to array-direct systems with high-volume storage, increased generator run-time during cloudy weather will be a necessity.

Access

Erik Lensch is the owner of Innovative Solar Solutions (www.innovativesolar.com), based in Charlotte, North Carolina. Formerly SC Solar, the company has been designing and supplying solar water-pumping systems since 1999.

Submersible Pump Manufacturers:

Conergy • www.conergy.us • DC pressure & surface pumps

Grundfos • www.grundfos.com • AC & DC/AC submersibles

Lorentz • www.lorentz.de • DC pumps & solar trackers

March • www.marchpump.com • AC & DC pressure pumps

Shurflo • www.shurflo.com • AC & DC pressure pumps & DC submersibles

SunPumps • www.sunpumps.com • DC pressure & submersibles