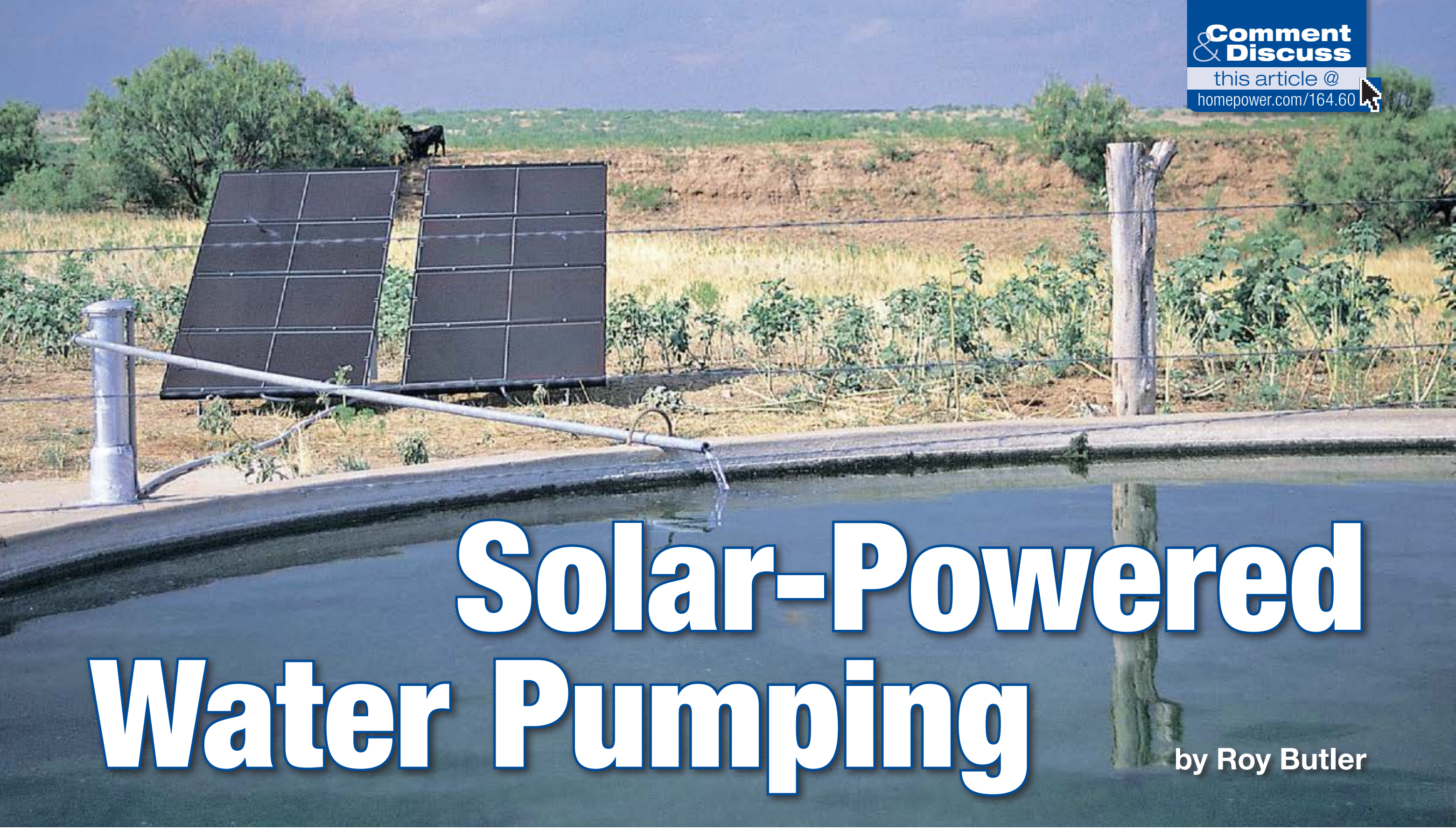


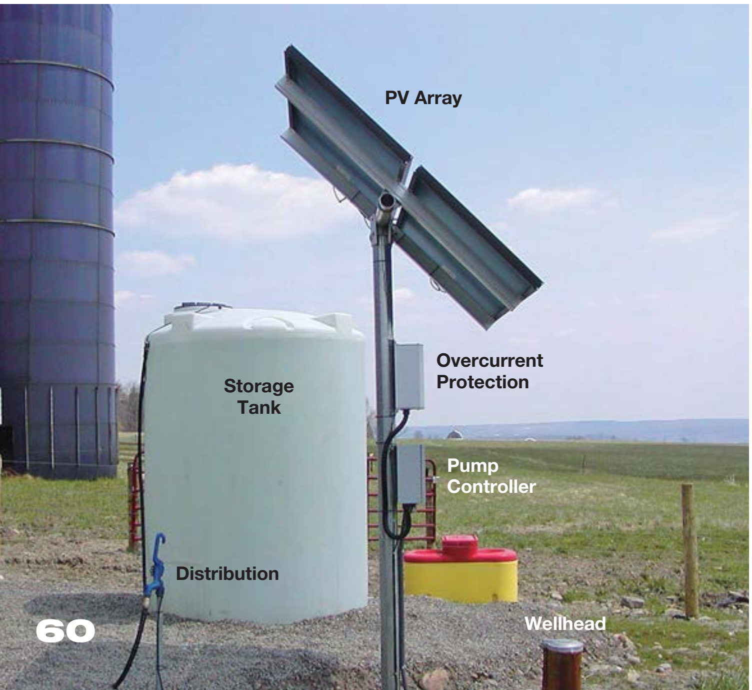
Solar-Powered Water Pumping

by Roy Butler

Courtesy Grundfos

Solar water pumps are a cost-effective and dependable method for providing water in situations where water resources are spread over long distances; power lines are few or non-existent; or fuel and maintenance costs are considerable.

Solar pumps are specifically designed to accept DC power directly from the solar modules and are optimized for operating under less-than-ideal sun conditions. Where conventional AC-powered pumps require a stable voltage and frequency to operate, solar pumps can operate over a wide range of voltage and available current.



Roy Butler

Conventional AC-powered pumps require large amounts of power to move large volumes of water in a short period of time. Solar pumps typically move a smaller volume of water over an extended period of time. This method requires far less power, which minimizes the size and cost of the PV array.

There are several methods for pumping water in remote areas, such as windmills, gas/diesel pumps, and ram pumps. But most of these options are either too expensive to install, or for fuel and maintenance, or require specific site conditions to operate.

Solar pumps can work for most locations and are at full capacity when needed most: during warm, sunny days. In temperate regions, they can be used year-round—which can be particularly helpful for potable water, animal grazing, and other farming operations. For many sites, a solar pump is often the best option for reducing cost and labor.

In areas with a remote well and limited access to the power grid, solar pumps are the best option—particularly where utility interconnection costs more than $5,000, usually about one-quarter to one-third mile from the grid. (In my area—western New York—the cost for utility power is about $10 per foot, so even PV-based water-pumping systems that are one-eighth mile from the nearest power line can be cost-competitive.) Specific applications include:

Domestic water supplies for off-grid homes and cabins. Although solar water pumps are used in this application, usually the home has an existing power system. In that case, it's far more cost-effective to run an efficient DC or AC pump off that system.

Livestock watering for pond and stream protection, rotational or prescribed grazing, and remote pasturing. This is the most popular use for solar pumping systems. They have proven to be cost-effective even without the use of federal or state incentives.

Aquaculture for aeration, circulation, and de-icing. Aquaculture is another application where the need for power coincides with peak solar availability. De-icing applications require oversized arrays due to less-than-optimum sun conditions in winter.

Irrigation for small-scale applications. With the recent reduction in the cost of PV modules, solar irrigation is fast becoming cost-effective. Solar pumps are available that can move the larger volumes of water needed for irrigation.

General System Types

In **PV-direct systems**, the PV array directly powers the water pump. With only three primary components—the array, pump controller, and pump—this can be a very affordable and low-maintenance system. As long as the sun is shining and the system is calling for water, the pump will run. For this type of system, adding water storage and/or oversizing the array for improved low-light operation is critical for most applications. There are three main options for PV-direct systems:

1) **PV-direct with gravity delivery or direct-to-source** (e.g., stock tank).This is the least complex and therefore usually the most cost-effective option. This system is well-suited for hilly terrain due to the ability to gravity-feed individual stock watering troughs from the primary tank.

2) **PV-direct to storage tank, with a booster pump for pressurized delivery.** This option has more complexity and cost due to its booster pump, pump accessories, and the need for extra PV power. Because it's not always possible or advisable to run two loads from one PV array, boosters are usually used on battery-based systems. These systems usually include a pressure tank so the booster pump does not have to run all the time water is being used.

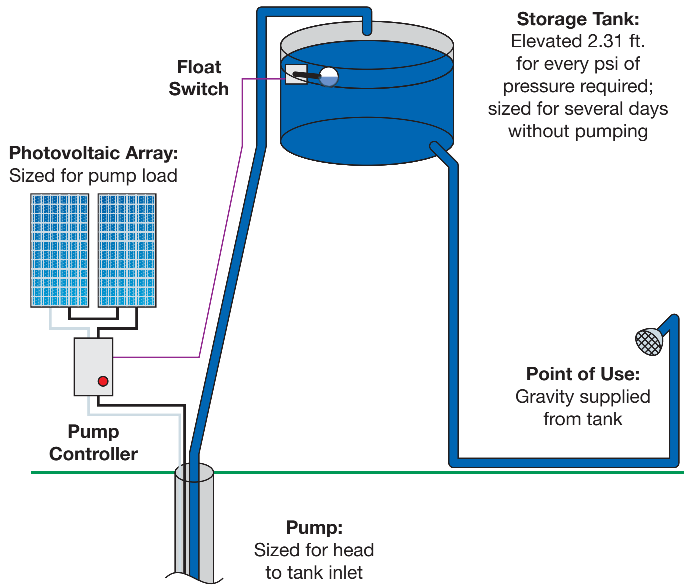
3) **PV-direct to an oversized pressure tank.** Although this system is fairly straightforward in the equipment that's needed, due to the addition of the pressure tank, it requires a pump and array sufficient to handle the additional total dynamic head (TDH; resistance to flow) from the pressure tank.

Battery-based systems (nighttime, pressurized, etc.) are fairly complex and, generally, the most expensive. This type of system is only recommended if full-time pressurized water is necessary.

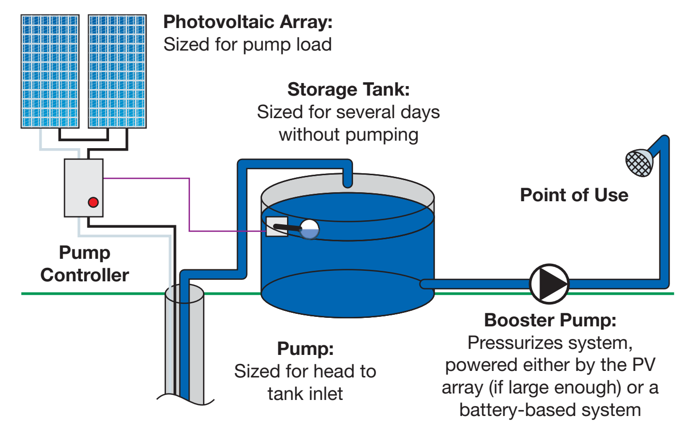
System Sizing

Determine needs. First, determine how much water you will need. If your needs vary during the season, be conservative and use the highest demand you expect (see the "Application & Water Use" table).

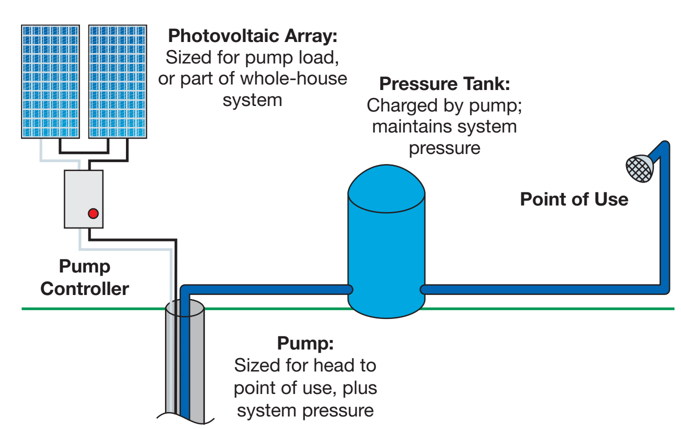
PV-Direct: Pumped to Storage, Gravity Distribution



PV-Direct: Pumped to Storage, Booster Pump Distribution



PV-Direct: Pumped to Pressure Tank for Distribution



Application & Water Use

Application	Approx. Usage (Gal./Day)
Household	50 per person
Cattle & horses	10–15 per head
Dairy cows	20–30 per head
Sheep & goats	2 per head
Small animals	0.25 per 25 lbs. body weight
Poultry	6–12 per 100 birds
Young trees	15 each, in dry weather

A surface pump can move large amounts of water, but because it has a limited draw depth, it is not usually used in drilled wells.

Determine source. The water system's configuration will be determined largely by the type of water source and its location. The source will either be subsurface (well) or surface (pond, stream, or spring). Wells are often preferred because of water quality and consistency—but they're expensive to drill, particularly where water tables are deep. Surface water sources may vary seasonally, often with low flow and quality during summer when higher volumes are usually needed.

For existing wells, the following needs to be determined (for new wells, consult the driller for this information):

- Static water level—the water level in the well under nonpumping conditions
- Seasonal depth variations
- Recovery rate—how quickly the well replenishes after pumping, measured in gpm
- Water quality (if for human consumption)

For surface water sources, the following need to be determined:

- Seasonal variations in water level, etc.
- Water quality, including presence of silt, organic debris, etc.

The water delivery system should be mapped out to show the location of the water source and the points of distribution. Include terrain contours to calculate the height differences. If the system is complex, find a water resource manager to help plan the water distribution system. Your local or county soil and water conservation district (SWCD), a branch of the USDA, is a great resource for this assistance.

Solar Siting

The water source site must then be evaluated for solar suitability. The following must be present for a productive PV system:

- A south-facing location with no significant shading
- Ample surface space for the pump, controllers, storage tank, and any other components
- A site for the solar array as close to the pump as possible to minimize wire size and installation cost
- If batteries are used, they must be in a reasonably dry/temperature-controlled location with proper venting
- If year-round water is required, freeze-proofing must be addressed. In a cold climate, a heated area is preferred for water storage and pressure tanks. (It is not economical to use PV to run a resistance heater in the winter.) In-well pressure tanks are sometimes used for freeze proofing.

PV arrays should maximize their direct exposure to the sun. That usually means in an area clear of shading, facing generally southward, and tilted at an angle about equal to the location's latitude. A tracker may be used to aim the PV array at the sun as it moves across the sky. This increases daily

This submersible pump is suspended from a raft near the center of this pond. Note the PV array that sits close to the pond's edge.

An in-well pressure-tank assembly for freeze protection.

Roy Butler (3)

energy gain by as much as 40%, depending on the latitude of the location (see “Tracking” sidebar). With PV module prices continuing to be some of the lowest in history, compare the cost of using a tracker versus adding additional modules on a fixed-mount system.

Assuming that you can locate the array in full sun, you then need to estimate the solar potential (daily sun-hours) using published data or maps. Multiply the array wattage by the number of expected peak sun-hours to get a rough estimate of daily energy available.

Tracking

A tracker for the PV array may be used to increase the power output by keeping the array pointed at the sun throughout the day. Passive trackers are preferred in remote locations where it is difficult to visually inspect equipment. A passive tracker has canisters of liquid on each end that are connected to each other by a tube. When the sun heats one canister, it turns some of the liquid to vapor and drives part of the liquid to the canister on the other side, and the weight difference causes the rack to tilt. When it faces the sun directly, both sides are equally heated and equilibrium is reached to stop movement.

A tracker can increase power output by 25% to 40%, reducing the number of PV modules required. The cost of the tracker with fewer modules should be compared to the cost of a larger stationary array. An additional benefit of a tracker is a potential reduction in pump stalling due to low-light conditions during late afternoon, low sun angles. This is of particular importance for systems that use a centrifugal pump, where water yield drops markedly with a drop in power. Trackers are favored in the summer months because of the sun’s longer arc of travel across the sky.

But trackers are not for every application. Their large surface area and the “wings” that block side sunlight can catch wind, so they should not be used in high-wind areas. Additionally, because it must be warm enough for the fluid to move from one side to the other, passive trackers may have difficulty tracking in the early morning and in extremely cold weather (below -10°F).

Courtesy SunPumps

Friction Loss in Schedule 40 PVC Pipe

Flow (GPM)	Head Loss in Vertical Ft. per 100 Ft. of Pipe, for Nominal Pipe Sizes (in.)					
	1/2	3/4	1	1 1/4	1 1/2	2
1	1.13	0.14	0.05	0.02		
2	4.16	0.35	0.14	0.05	0.02	
3	8.55	2.19	0.32	0.09	0.05	
4	14.80	3.70	0.53	0.16	0.09	0.02
5	22.18	5.78	0.81	0.25	0.12	0.04
6	31.08	7.85	1.00	0.35	0.18	0.07
7		10.60	1.52	0.46	0.23	0.08
8		13.40	1.94	0.58	0.30	0.09
9		16.90	2.43	0.72	0.37	0.12
10		20.30	2.93	0.88	0.46	0.16
12		28.60	4.11	1.22	0.65	0.21
14			5.47	1.64	0.85	0.28
16			7.02	2.10	1.09	0.37
18			8.73	2.61	1.34	0.46
20			10.60	3.16	1.64	0.55
22			13.30	3.79	1.96	0.67
24			14.90	4.44	2.31	0.79
26				5.15	2.66	0.90
28				5.91	3.05	1.04
30				6.72	3.46	1.18

Note: Shaded values are over 5 ft. per second & should be selected with caution

Source: dankoffsolarpumps.com

Determine Total Dynamic Head (TDH)

Once you know the amount of water needed, the water source’s characteristics, the distances (both vertical and horizontal) that the water will be pumped and the pipe size, you can determine the size of pump and PV array. You first need to calculate the value of TDH, which is the sum of the height from the water level to the storage tank top, plus friction losses. For submersible pumps, TDH is not calculated from the pump depth, but from the static water level less any draw-down that occurs when the pump is running.

Friction losses are the resistance to water flow on the inside surface of the pipe and fittings. The smaller the pipe and the greater the pumping rate, the higher the friction loss, expressed in equivalent height.

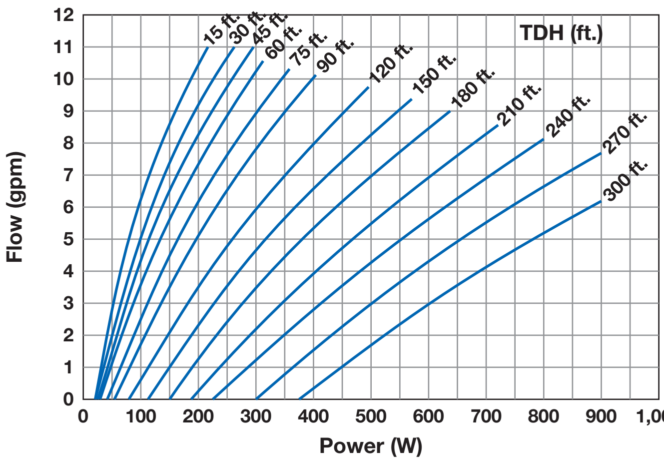
To calculate the required pumping capacity, use the following equation:

Pump capacity = (Gallons/day ÷ daily peak sun-hours) ÷ 60 min./hr. = XX gallons per minute

For example, if your water needs are 1,500 gallons per day and you have determined that the site has 5 peak sun-hours per day during the grazing season, you need a minimum pumping rate of 5 gpm.

A friction-loss table (see above) uses the pumping rate and the pipe’s inside diameter to give friction loss in vertical feet for every 100 feet of pipe. For example, if you are using 300 feet of 3/4-inch pipe at 5 gpm, you would need to add 17.34 feet (5.78 × 3) to the total lift height.

Grundfos 11 SQF-2 Pump Performance



Courtesy Grundfos

This Grundfos controller operates on AC or DC, and in a variety of voltages.

Determine Pump & PV Array Sizes

Using the TDH and desired gpm, refer to the pump manufacturers' graphs to determine the pump wattage necessary. To size the PV array, some pump manufacturers require you to increase the specified pump's wattage by 25% (multiply by 1.25) to compensate for array power loss due to high heat, dust, aging, etc. Some solar pump companies, such as Grundfos, offer an online sizing tool that already accounts for PV array losses.

Small 12- and 24-volt DC pumps will require the use of lower-power modules that are typically more expensive than higher-power modules. Larger pump systems that require higher-voltage arrays, and battery-based systems that use MPPT charge controllers can use less expensive, more commonly available modules. For a detailed example of system sizing, see "Methods" in this issue.

Pump Controllers

The pump controller includes an electronic linear current booster that acts similar to a maximum power point tracker controller, optimizing power to the pump despite wide variations in solar power production. It is particularly helpful in starting the pump in low-light conditions. Most manufacturers require the use of their proprietary controllers with their pumps.

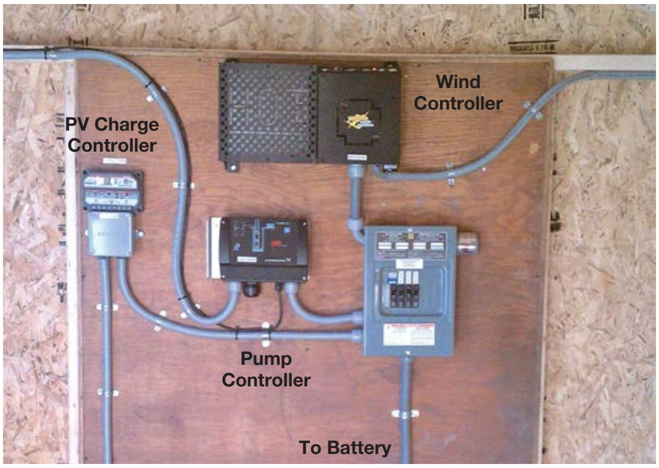
Most controllers have the capability to control pump operation via a float switch or pressure switch. System status and diagnostic displays are also common.

Charge Controllers

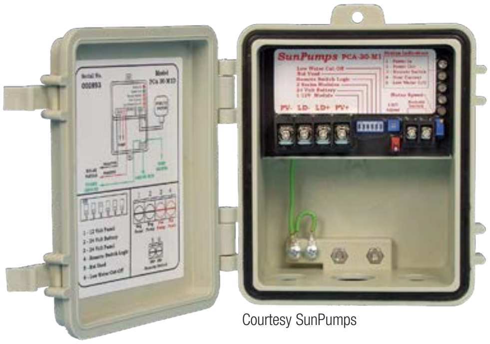
When batteries are included, a charge controller is needed to keep the batteries from overcharging or overdischarging. Basic pulse-width modulated (PWM) controllers are typically used for small 12- and 24-volt battery systems. These have a fairly narrow voltage input window, so properly matching the modules to the controller is critical. Maximum power point tracking (MPPT) charge controllers can use higher-voltage module strings, which allows choosing from a wider range of modules. Where long wire runs between the array and pump are required, the higher-voltage strings allow using smaller wire, which reduces system cost and minimizes voltage drop.

Load control is another feature found in many charge controllers. The most common load control is a low-voltage disconnect (LVD), which prevents damage to the batteries by turning off the pump if the battery voltage gets too low due to deep discharge. Another use is to divert the PV power to run another load if the batteries are full, allowing full use of the array's potential.

Battery-based pumping systems provide water when the sun isn't shining, but add cost and complexity.



Roy Butler



Courtesy SunPumps

This SunPumps controller can run PV-direct or from batteries, and includes remote switching and a low-water cutoff.

Tank Storage

Most solar water-pumping systems use some type of storage. A general rule is to size the tank to hold at least three days' worth of water to balance variable sun conditions. With too much storage or too long, water quality issues such as algae growth may arise. To prevent algae growth, a maximum storage of two days is recommended if the tank is in full sun; if the tank is shaded, a maximum of three days of storage is advised.

Food-grade plastic tanks are most common, and often placed at a high point on the property for gravity-feed to the end use. Although these tanks are usually the most affordable option, sun exposure tends to promote algae growth in them.

A better but more expensive option is a buried cistern. A cistern offers freeze protection, stabilizes water temperature, and minimizes poor water-quality issues. A float switch inside either type of tank controls the pump according to water level. A wire is run alongside the fill pipe from the float switch to the pump controller.

Pressurized Water Systems

In some applications, a pressurized water system may be required. For example, most freezeproof livestock watering stations require a constant water pressure of at least 3 to 5 psi to keep the ground convection loop active. A properly sized solar pump can pressurize a water system much the same as a standard AC-powered pump. If water is needed day and night, the pressure tank can be oversized to provide water through the night. A pressure-operated switch turns the pump controller on and off according to tank pressure.

If more capacity is needed than an oversized pressure tank can provide, batteries can be added to provide energy when solar is not available—the PV array recharges the batteries each day. A charge controller and low-voltage disconnect are needed in this type of system. The complexity and maintenance considerations of this type of system make it one of the more costly solar pumping options.


Roy Butler

A float switch hangs on a weight inside a storage tank.


Courtesy Conergy

A typical pressure switch can control a PV-powered pump.


Roy Butler

Aboveground poly tanks are inexpensive and durable. White ones stay cooler, but allow light to penetrate, which can cause more algae growth.

Solar Pumps

Most conventional AC pumps use a centrifugal impeller that "throws" the water into motion. A multistage centrifugal pump has a series of stacked impellers and chambers. When operating at low power, the output of centrifugal pumps drops dramatically. This makes centrifugal pumps somewhat limited for solar applications, though more-efficient centrifugal pumps are available. Solar centrifugal pumps are capable of high flow rates but are limited in vertical lift capabilities. They also require fairly large PV arrays. These pumps are ideal for low-head irrigation applications.

Positive displacement pumps, which bring water into a chamber and then force it out using a piston, rotating chambers, or a helical screw, are often used as solar pumps. These generally pump more slowly than centrifugal pumps, but have good performance under low-power conditions and can achieve high lift and pressure. These are ideal for small livestock, pond aeration, and small potable water systems.

Even a few feet of height can give a tank enough head for low-pressure gravity distribution.


Roy Butler

Manufacturers

Advanced Power • solarpumps.com
Aquatec • aquatec.com
CAP Solar • capsolar.com
Dankoff Solar Pumps • dankoffsolarpumps.com
Grundfos • us.grundfos.com
In-Well (No Tank) • inwelltech.com
Lorentz • lorentz.de
Mono Pumps • mono-pumps.com
Shurflo (Pentair) • shurflo.com
Sunmotor International • sunmotor.ca
SunPumps • sunpumps.com
SunRotor • sunrotor.com

SunPumps' SCB 10-185 DC surface pump.

Courtesy SunPumps

This Lorentz pump controller converts DC to three-phase, variable-frequency AC. Pictured next to the controller is a three-phase AC submersible pump.

Courtesy Lorentz

Although a submersible pump remains underwater, such as in a well, it can also be used for some surface water applications. A suction-type surface pump is mounted at or just above water level, and is excellent for pushing water long distances. Surface pumps are less expensive, but are not well-suited for suction—they can draw water from only about 10 to 15 vertical feet. They are also not dirt- and debris-tolerant, and typically require filtration.

Solar pumps are available in a wide range of types and sizes. The right pump is determined by carefully calculating your needs. For example, one of the smaller solar DC surface pumps requires a PV array of just under 150 watts and can pump at 1.5 gpm. During 10 sunny summer hours, it can pump up to 900 gallons—if it has full power the entire time. A submersible DC pump, with 300 W of PV modules, might pump more than 1,100 gallons in about 5 hours from a 150-foot-deep well. The equivalent 3/4 hp, 240 VAC pump would require 2,000 W of PV modules, an inverter, and batteries to pump this amount of water in one hour.

Adapted, in part, from the "Guide to Solar-Powered Water Pumping Systems in New York State" by Roy Butler, Christopher Sinton & Richard Winnett.