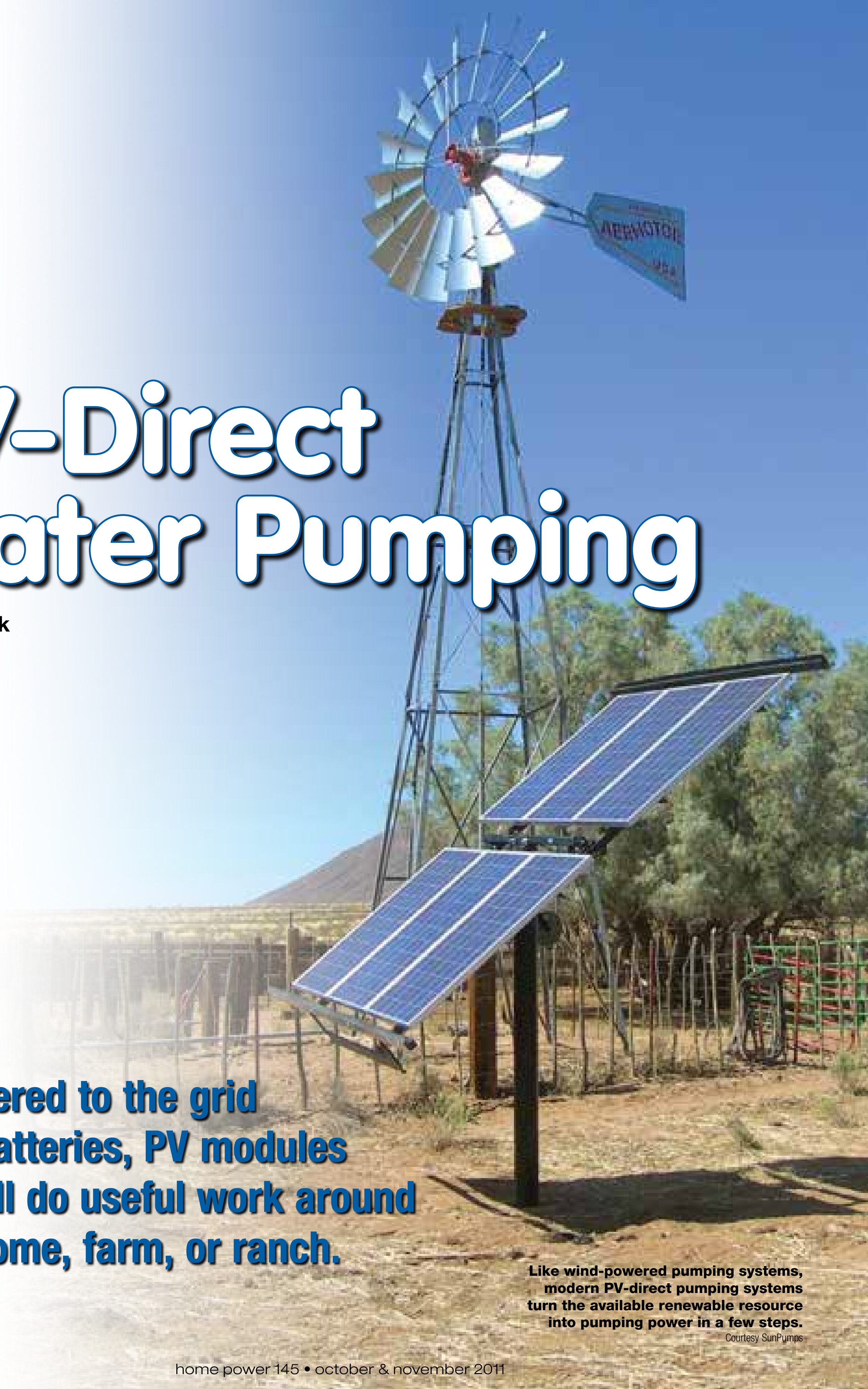
PV-Direct Water Pumping

by Dan Fink

Untethered to the grid or to batteries, PV modules can still do useful work around your home, farm, or ranch.



Like wind-powered pumping systems, modern PV-direct pumping systems turn the available renewable resource into pumping power in a few steps.
Courtesy SunPumps

PV systems that power loads directly from a PV module or array are called "PV-direct," and operate only when the sun is shining. These systems are much less expensive and easier to install than battery-based or grid-tied designs. They do not require batteries, charge controllers, or inverters, all of which are expensive and reduce overall system efficiency.

The most common PV-direct application is solar water pumping for irrigation, livestock, and domestic use. If water is what you need, why bother with batteries? Water tanks are far cheaper than battery banks, and last for decades. These systems work well as long as you can store enough water to get you, your plants, and your animals through periods of no sun. PV-direct pumping is not used to provide domestic water pressure, but usually to fill a tank. Gravity or a separate, inexpensive water pressure-pump system is instead used to push stored water to your household faucets, shower, etc.

Water pumps for PV-direct use come in a several varieties:

- **Surface pumps** are used to move water from sources like shallow wells, ponds, streams, and tanks, where the pump itself is located no more than 20 feet above the water level. There are many types available; your choice will depend on how much water per day you need to move, how high, and how far.
- **Submersible pumps** are for deeper wells, where the pump can't be installed within 20 feet above the water level. These pumps are suspended below the water level in the well and connected to an output pipe that extends up to the surface. Once again, the right pump for your application depends on your needs for quantity of water and pumping height and distance.
- **Circulation pumps** are used to move water around in a closed system, such as solar water heating for domestic water, space heating, pool, or spa. They generally lift water only a short height.

Why is there a 20-foot height limit from a water's surface to pump? Pumps can *push* water up hundreds of feet and move it horizontally over great distances, but must rely solely on atmospheric pressure to "suck" water up to their level for pumping to the final destination. The theoretical limit is 33.9

This SunPumps submersible pump is designed to be suspended deep in a well, and can be powered directly by a PV array.

Courtesy SunPumps (2)

A DC surface pump (below) is often built for higher flows, but usually cannot draw water more than 20 vertical feet, making it highly suitable for moving water from surface sources like the irrigation pond (at right).

Courtesy Innovative Solar

PV-direct systems turn the sun's rays directly into useful work, but a pump controller is used to turn the pump on and off, and can optimize the system's performance.

Linear Current Boosters

Electric pump motors require extra power to start spinning—up to four times the power used to just run. Many pump controllers have linear current booster (LCB) circuitry, trading volts for amps (and vice versa) to run the pump at its most efficient rate for the amount of power the PV array is producing. On an overcast day, a pump with no LCB may be sitting idle, while a pump with an LCB can overcome the required startup load and then run all day, albeit at a slower rate, proportional to solar intensity.

feet (10.3 meters) at sea level, but even the slightest vacuum leak will drastically reduce that limit, as will high altitudes. As little height as possible, with a maximum of 20 feet (at sea level), is a realistic guideline.

Pump Controllers

In the simplest PV-direct application, a controller may not be required—when the sun shines, the pump runs, and when the sun sets, the pump stops. But in most systems, a controller is wired between the PV array and the pump to stop water flow when the tank is full and to prevent running the level of the water source so low as to run the pump dry.

To sense water level, float switches are wired to the controller and they use gravity to open or close contacts as the float angle changes with water level. Most are intended to switch the entire current of a typical 120- or 240-volt AC pump, and may not function properly with the low-voltage, low-amperage sensing circuit in the solar pump controller. Be sure to get the right switch for your application. For irrigation, there are other switches available, such as soil-moisture sensors to prevent over-watering, and high-wind sensors to shut the system down when winds might spread water to where it's not wanted.

System Sizing

The easiest way to determine the size and cost of a PV-direct water-pumping system is to ask your favorite renewable energy dealer! They will have spreadsheets and product specifications handy, and be able to do the math quickly for you. It never hurts to do your homework, though, so you have a rough idea of how much you'll have to invest. In any case, you'll need some critical information to get an accurate cost estimate.

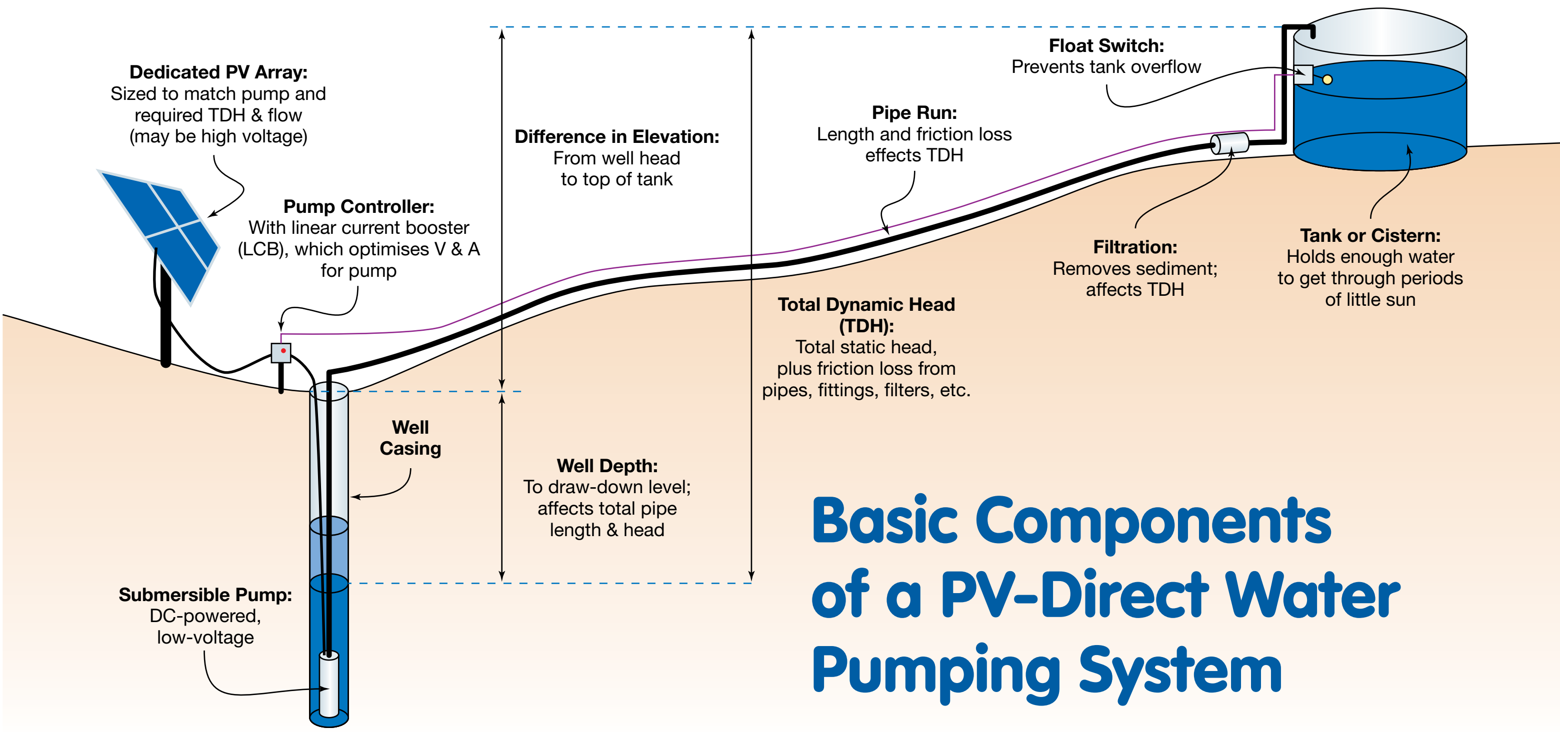
First, you'll need to know how much water you need to move per day, and size your storage tank to get you through both nighttime and periods of cloudy weather when the pump won't be running (or is running slowly). Next, you'll need to calculate your system's total dynamic head (TDH). This is the sum of the **static head** (total vertical distance from water surface to discharge outlet), **friction head** (friction losses from pipe walls and bends in the pipe), and **pressure head** (losses from any nozzles or filters in the lines). Head can be expressed in either feet of water or pounds of pressure per square inch.

Head (in ft.) ÷ 2.31 = psi
Head (in psi) × 2.31 = Head (in ft.)

Static head needs to be measured to an accuracy of ±1 foot, which can be done using a level and rod. Topographic maps or GPS measurements are not accurate enough. A sight level with a measuring rod or some other means is necessary. (For more info on measuring head, see "Intro to Hydropower" in *HP104*). If you have a deep well, the driller should have provided you with the distance from ground level down to water level. If not, they can come back to measure it (they use a special sensor) or you can come up with your own measurement solution. Well draw-down—how far the water surface level drops while you are pumping water—also affects static head measurements. Your well driller should have also provided you with this information right after the well was drilled and the pump installed, and also the rate (in gallons per minute; gpm) at which the well refills.

PV-direct pumping systems can provide domestic water at remote sites, utilizing only a small PV array.

Courtesy SunPumps (2)



Basic Components of a PV-Direct Water Pumping System

Example Pipe Friction Loss

Flow (GPM)	Polyethylene (PE): PSI per 100 ft.					
	1/2 in.	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	2 in.
1	0.49	0.12	0.04	0.01	0.00	0.00
2	1.76	0.45	0.14	0.04	0.02	0.01
3	3.73	0.95	0.29	0.08	0.04	0.01
4	6.35	1.62	0.50	0.13	0.06	0.02
5	9.60	2.44	0.76	0.20	0.09	0.03
6	13.46	3.43	1.06	0.28	0.13	0.04
7	17.91	4.56	1.41	0.37	0.18	0.05
8	22.93	5.84	1.80	0.47	0.22	0.07
9	28.52	7.26	2.24	0.59	0.28	0.08
10	34.67	8.82	2.73	0.72	0.34	0.10
11	41.36	10.53	3.25	0.86	0.40	0.12
12	48.60	12.37	3.82	1.01	0.48	0.14
14	64.65	16.46	5.08	1.34	0.63	0.19
16	82.79	21.07	6.51	1.71	0.81	0.24
18	102.97	26.21	8.10	2.13	1.01	0.30
20	—	31.86	9.84	2.59	1.22	0.36
22	—	38.01	11.74	3.09	1.46	0.43
24	—	44.65	13.79	3.63	1.72	0.51
26	—	41.79	16.00	4.21	1.99	0.59
28	—	59.41	18.35	4.83	2.28	0.68
30	—	67.50	20.85	5.49	2.59	0.77
35	—	—	27.74	7.31	3.45	1.02
40	—	—	35.53	9.36	4.42	1.31
45	—	—	44.19	11.64	5.50	1.63
50	—	—	53.71	14.14	6.68	1.98
55	—	—	—	16.87	7.97	2.36

Source (includes tables for other pipe types):
www.hunterindustries.com/Resources/PDFs/Technical/Domestic/LIT091w.pdf

Horizontal distance from pump to discharge outlet can be measured with a tape, but **friction head** calculations involve complicated math that includes flow rate; pipe diameter, length, and smoothness; and any fittings in the line. Fortunately, friction head can be estimated using tables provided by pipe manufacturers. There are also numerous friction-loss calculators available online. If you are pumping from a well, be sure to include the pipe length from the pump to ground level in your total distance.

Because typical, home-sized PV-direct systems pump slowly, you can safely assume a pipe diameter of 3/4 to 1 inch, and adjust this later as you narrow down which pump you need. Using very large diameter pipe (greater than 2 inches) is not recommended in small systems—it's expensive, and with low flow you may have sediment buildup inside the pipe.

For **pressure head**, the manufacturer of the irrigation nozzle or water filter you are planning to use will provide you with pressure drop data, in pounds per square inch (psi).

Lastly, you'll need to find out the average number of full-sun hours your site receives each day. You can look up your location on an insolation map online (http://rredc.nrel.gov/solar/pubs/redbook), or use PVWatts, NREL's online calculator. With this information, you can get a quote from a solar pump dealer.

Selecting a Pump

The common design philosophy behind PV-direct water pumping is simple: Pump slowly with as few PV modules as possible, and install a big storage tank. PV-direct pumps in home-scale systems generally operate in the range of 1 to 4 gpm, while typical AC well pumps usually work at 6 gpm and up. These pumps are *not* suitable for PV-direct use—they require a battery bank, an inverter with high surge capacity,

Other PV-Direct Applications

Water pumping is certainly the most common PV-direct application, but there are others that are also a perfect fit.

Water aeration is used to oxygenate or prevent freezing in ponds. Some systems use water pumps and fountains; others use compressed air.

A simple air compressor on shore and diffuser system at the bottom of the pond, powered directly by a PV module, can be very effective at keeping the water from freezing. Rising air bubbles bring warmer water from the bottom up to the surface, and aquatic life in eutrophic ponds with insufficient dissolved oxygen levels can also benefit from aeration.

Sizing a PV-direct compressor/aeration system is very similar to sizing a water-pumping system. Instead of total dynamic head, you'll be calculating air pressure drop (from pump depth and air tubing size), and the flow per minute will be measured in cubic feet instead of gallons. Instead of a pump curve, you'll consult a compressor curve. But all the basic system design concepts remain the same, and purpose-built, efficient DC compressors are readily available. Water fountain aeration systems are sized using the same math as in other water-pumping applications.

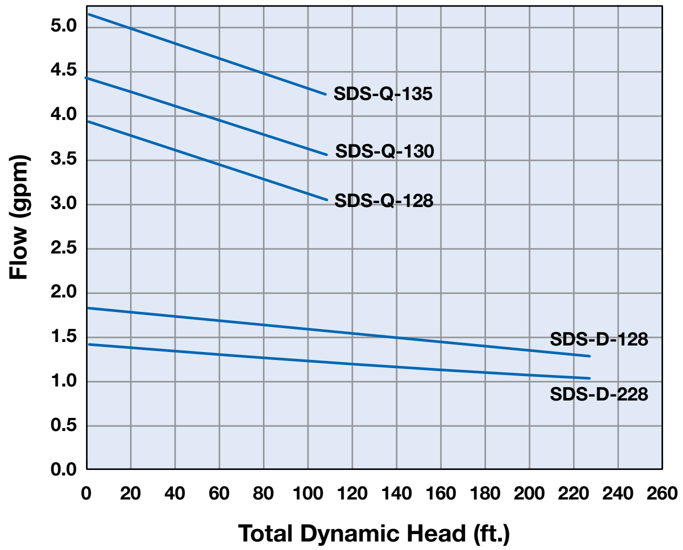
PV-direct water or air pumps can provide aeration and/or freeze protection.

PV-direct ventilation systems, such as greenhouse fans and attic fans, are also popular, and can be a very logical and cost-effective application—the more intense the sunlight, the more airflow is typically needed in an attic, greenhouse, or other structure. Systems retain the same similarities in design—the blower, controller, and PV array must all be matched to the duct size and pressure losses. Efficient, purpose-built PV-direct DC blowers are easy to find.

Courtesy SunPumps (2)

The stronger the sun shines, the more air this PV-direct ventilation fan exhausts.

Example Pump Specifications



and a larger PV array. If you already have one of these pumps in your well, you'll need to replace it to use PV-direct pumping. Most solar pump manufacturers provide graphs of specifications for their pumps, grouping model series on one graph to make selection easier.

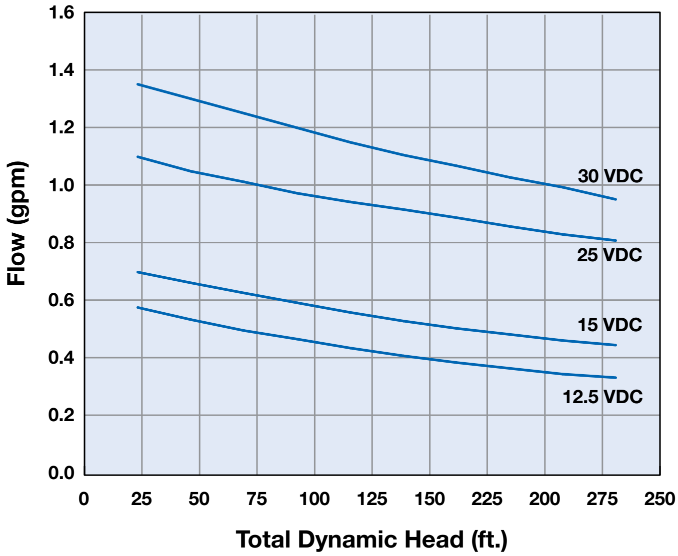
For example, let's say you need about 240 gallons of water per day for domestic, livestock, and irrigation use. From well draw-down level to the cistern, the water must be lifted 60 feet over a distance of 500 feet. You have 3/4-inch polyethylene pipe ready, and a sediment filter at the tank causes a pressure drop of 2.41 psi. The well refills at 3 gallons per minute. Your average daily insolation during the worst month of the year is 4 sun-hours, and you need enough water to ensure cloudy periods of up to 7 days.

Working backward with storage capacity, you'll need a 1,680-gallon water storage tank (240 gal./day × 7 days). The flow rate required would be about 1 gallon per minute [240 gal./day ÷ 240 min./sun-hours day (the number of minutes in 4 hours)]. Because the well refills at 3 gpm, there is no chance you'll run the pump dry.

Next, calculate total dynamic head (TDH). The total pipe length is 560 feet (500 ft. horizontal + 60 ft. vertical). The 2.41 psi pressure drop from the filter adds 1 foot of TDH, and pipe friction at 1 gpm adds another 1.55 feet, for a total of 62.55 feet of TDH. There are also unknown factors, such as the friction from pipe connectors and valves. A safe estimate is 70 feet of TDH—always oversize your system.

The lines on a pump manufacturer's graph (above) show the maximum output the pump can produce at a given head and flow. Find the intersection of 1 gpm flow and 70 feet of head on the graph. That spot sits nicely below the curve of the example SDS D-series pumps, and far below the more expensive SDS-Q series. In this example, then, the D-series would be a better investment.

PV / Pump Voltage Selection



Sizing the PV Array

The final piece of the puzzle is calculating the size of the PV array required to run the pump at the specified head and flow rate. Again, the pump manufacturer can provide the specs for you.

Most home-scale PV-direct applications require between 100 and 800 watts of PV, depending upon the site and the needs. You should always oversize the PV array by at least 20% to make up for electrical and mechanical losses in the system. If your calculations indicate a PV system larger than you can put in, you might save money with a smaller array and a pump with slower flow—but spending a little more on a larger water tank.

In the example given, use the pump manufacturer's voltage and capacity chart (above) to size the PV array. In this example, 1 gpm at 70 feet TDH is too much to run PV-direct from a single 17-volt PV module—the spot where gpm and TDH cross is above the graph line. At 34 V module-direct, though, capacity is more than ample; the manufacturer calls for 72 W of PV. Two 50 W, 17 V modules in series would be ideal.

For some systems, using a tracker so the PV array follows the sun to increase the energy output may be worth considering, though it will add expense and more moving parts to the system. If most of your water-pumping needs occur during summer when trackers yield the most benefit, you can calculate how cost-effective tracking would be by using NREL's online insolation calculator and examine scenarios using single- or dual-axis trackers. Even without using a tracker, consider using a mount that can be adjusted seasonally.

Electrical Considerations

Depending on the pump and controller/LCB that you choose, different PV array wiring configurations may be possible. It's always better to use higher voltage at the array, as wire size and cost are decreased—array voltages of more than 150 volts are possible, combiner boxes may not be needed, and pump motors operate more efficiently at higher voltages. The LCB steps this down to something lower (usually 12 to 48 volts) near the pump. A high-voltage PV array is less costly to locate farther from the controller to give more choices for siting, and can be connected with smaller-gauge, less-expensive wire.

PV-direct systems can often be installed without a structure to house the equipment. Be sure that all electrical equipment is installed and wired with weatherproof, outdoor-rated boxes and connectors. Follow the manufacturer's recommendations for overcurrent protection for the pump and controller. PV-direct systems should be grounded to *National Electrical Code* specifications. That may entail two ground rods—one for the PV array frames, rack, and pole; one for the pump, controller, and electrical boxes—depending on distance and other factors. Grounding is a complicated issue, so be sure to consult with a system designer, electrician, or local electrical inspector.

Like any renewable energy investment, PV-direct systems require research and design before the first PV module and pump is purchased and installed. Because each component must be carefully matched to the others and to the load, proper planning is essential—so the results will be an efficient, reliable system that will be functioning for years to come.

Access

Author and educator **Dan Fink** (danfink@buckville.com) has lived 11 miles off the grid in the northern Colorado mountains since 1991. He teaches about off-grid systems and small wind power, and is the executive director of Buckville Energy Consulting, a NABCEP/IREC/ISPQ-accredited continuing education provider. Dan is the coauthor of *Homebrew Wind Power.*

Pump Manufacturers:

ACS-Solarsystems • www.acs-solarsystems.com/Solar_Pumps.htm
Aquatec • www.aquatec.com
Hartell • www.hartell.com
Innovative Solar (Dankoff Solar Pumps) • innovativesolar.com
Ivan Labs Inc. (El-Sid) • 561-747-5354
Laing • http://lainginc.itt.com
Lorentz • www.lorentz.de/
LVM • www.ittflowcontrol.com/alternative-energy/
March Pumps • www.marchpump.com
SHURflo •www.shurflo.com
Solar Converters Inc.• www.solarconverters.com
SunPumps Inc. • www.sunpumps.com

Solar Ventilation Fans:

Natural Light • www.solaratticfan.com
Snap Fan • www.snap-fan.com
SunRise Solar • www.sunrisesolar.net

Pump Controls/Linear Current Boosters:

AeroVironment • www.avinc.com
BZ Products • www.bzproducts.net
SunPumps Inc. • www.sunpumps.com