

Solar Power Livestock Watering Project for Pennsylvania

INTRODUCTION

A project to demonstrate the use of photovoltaic (PV) solar technology on typical Pennsylvania livestock farms for water pumping was conducted over a two and one-half year period beginning in March 1999. Twenty-seven solar pump systems were installed on a variety of livestock operations including dairy, beef, and sheep. The systems were each unique given the very diverse sites around Pennsylvania in which they were installed.



The primary objective was to advance the concept of intensive rotational grazing and thus reduce the need for mechanical harvesting and its inherent consumption of fossil fuels. Since water supply is one of the most critical components, second only to fencing, in establishing rotational grazing systems, it was determined that a cost effective and reliable means of moving water to and from remote locations needed to be identified and demonstrated. Solar power appeared to be a reasonable choice primarily because of its inherent non-polluting characteristic.

On most Pennsylvania farms, water is available but it is seldom located where it will support properly designed and managed grazing systems, therefore it must be moved via pipelines using either gravity or mechanical means. Since water is typically found at lower elevations than is practical for use in most rotational grazing systems it generally needs to be pumped. And, since most under-utilized grazing lands are often very remote and at great distances from grid-power sources, alternative energy sources must be used to power the pumps.

The use of solar energy to pump water for livestock, although popular and successful in the western United States, is a relatively unproven technology on Pennsylvania farms. This is likely due to the fact that most of Pennsylvania lies within a relatively undesirable solar energy zone where there is a significant occurrence of overcast and somewhat cloudy days. Therefore most landowners have been skeptical about the reliability of solar power and reluctant to invest in this technology that has not been proven to operate efficiently under these conditions. Likewise, the cost of direct current (DC) pumps and solar components has generally limited experimentation to all but the most innovative and technologically savvy farmers. Generally these were the individuals that participated in this project.

APPROACH

The project utilized the technical expertise of the Natural Resources Conservation Service (NRCS) conservationists and technicians to identify interested livestock farmers and to conduct preliminary site surveys to determine site suitability. NRCS regularly assists these landowners and has the technical expertise to develop and install various types of conventional watering systems and to design rotational grazing systems. The opportunity to work with solar powered water pumping systems was perceived as a means of expanding NRCS technical capabilities to assist their clients. At the same time it was a means of promoting the use of solar power beyond the duration of this project through the experience and knowledge gained by the NRCS staff that participated in the project.

To initiate the project it was necessary to locate solar component suppliers and installers. With the aid of the Internet, this was accomplished but, as expected, the availability of system components and the number of qualified system installers in Pennsylvania were extremely limited. Despite a very limited response to a request for proposals, we were fortunate to secure the services of two solar component supplier/installers only one of which was actually located in Pennsylvania. It became very apparent, early in the project, that the availability of technical support was going to be the critical element that would determine either the success or failure of the project. The technical assistance required was for these primary tasks :

1. Identification of interested landowners with suitable sites.
2. Planning of rotational grazing systems.
3. Survey and design of the water delivery system.
4. Design and installation of the solar component portion of the system.

It was originally planned to have the field office staff of NRCS only carry out the first three tasks. However, due to the limited availability of the supplier/installers it was necessary for NRCS staff to provide technical assistance on design and installation of the solar components for several of the installations. The solar component suppliers did provide limited training and telephone consultation to the NRCS staff; however, this was determined to be only marginally adequate due to the complexity of the solar component circuitry (primarily with respect to the pump controllers). For the complex and problem installations, the professional installers were retained for the actual installations and trouble shooting.



During the first year only diaphragm type submersible pumps were used. This greatly simplified the design and installation of the systems. However, it also limited the participation in the project because these pumps were not able to lift water to the necessary elevations or supply the required volumes of water for many of the livestock operations. These pumps did, however, perform very well where site conditions and livestock water requirements did not exceed the pump's design capacities. Aside from design simplicity, the major reasons for selecting diaphragm pumps were as follows:

1. Adaptability to all water sources including wells
2. Relatively low power requirements – i.e. solar arrays sized between 100 to 200 Watts
3. Relatively low cost compared to other DC pumps - A critical factor during the first year when we operated with a Department of Energy grant requiring a 1:3 grant to local match ratio

The pumps and solar components were purchased through a “low bid” process from the two selected suppliers during the first year.

The project was redesigned for the second year. This included an improved grant structure that only required a twenty-five percent local match. Additional types of pumps were added including piston, vane, sucker rod, centrifugal submersible and helical rotor pumps. This significantly increased the adaptability of the solar water-pumping project to Pennsylvania's wide variety of site conditions; however, it also increased the costs and complexities of the systems. Larger arrays of solar panels were required as well as more costly pump controllers. The project redesign also permitted farmers to purchase the pumps and solar components from any vendor of their choice. These changes did accomplish the main objective for the redesign, that being to entice more livestock farmers to participate.

REQUIRED DESIGN CRITERIA

1. Determine the quality and quantity of available water
2. Compute the daily water requirements of livestock on pasture
3. Measure the elevation difference between the water source and the proposed storage tank
4. Select a pump that will deliver the required daily volume of water
5. Compute Total Head as: Δ Elevation + (0.03 x linear distance)
6. Design the solar array using pump wattage requirements for the specific pump working at the specified total head. Add no less than 25% to the required pump operation wattage to promote easier/earlier starting of pumps with PV-Direct systems. Add more for smoother operation on overcast days.
7. Locate the solar modules where they will get full sun all day and as near to the pump as possible reduce the cost of wire. Greater distance requires larger gauge wire that is typically very expensive.
8. Measure the distance from the solar array to the pump. Size wire to result in no more than a 2% voltage loss using a DC Voltage Loss Chart
9. Size the storage tank to hold three or more days supply of water

THE SOLAR COMPONENT INSTALLATIONS

Although numerous pump types and water sources, including springs, ponds, streams, and wells, were utilized; the design principles for all installations were relatively the same. This dominant principle relates to the fact that it is more cost effective to store water than to store electricity. Therefore, all systems were recommended to be operated PV-direct. That is to say that batteries were not recommended (although one, to be described later, was installed and subsequently removed), therefore the solar arrays were wired directly to the pumps through the pump controllers. This is the most efficient use of solar electric energy. The stored energy was in the form of water stored in tanks located high on hills.

The **solar arrays** were typically wired for 24-volts although a few systems were wired for 12, 36, and 48-volts. Each solar panel is manufactured to produce 12-volts DC so for 24-volt systems it required two panels wired in series. Two series pairs were combined in parallel on four panel arrays for additional power requirements. Most systems were two or four panel arrays mounted on specially designed racks and typically supported by a single metal pole. Tracker type racks were used on two installations to maximize power by enabling the array to follow the sun's movement across the sky. Most



installations, however, used stationary arrays that were oriented due south. The individual solar panels ranged in size from 50 to 80-watts with the resulting array wattage ranging from 100 to 320-watts. The arrays were sized to provide the wattage required by the selected pump plus twenty-five percent extra to aid in kick-starting the pump. It was found that this 25% was critical for our installations due to our commonly occurring overcast skies. Extra array capacity beyond the 25% allowed the pumps to operate even more efficiently under the overcast skies. The individual solar panels were wired with 12-gauge braided wire. The solar electric current was wired into a disconnect box that included a lightning arrester and then to the pump controller. Depending on the distance between the solar array and the pump, wire size ranged from #10 AUW to #4 AUW.

The pumps were sized to deliver at least one day's water requirement for the livestock to be supported. The design criteria included both delivery rate and the elevation to lift the water. The size and type of pump plus the required lift dictated the size of the solar array. Typically 1.25-inch to 1.5-inch rolled plastic pipe was used to deliver water from the source to the storage tank.

The **submersible diaphragm pumps** were available in two models. The duplex model (two diaphragms) is capable of lifting water 230 feet and has a maximum delivery rate at lower heads of two gallons per minute (gpm). The quad model (four diaphragms) delivers up to 3.8 gpm with a maximum lift of 100 feet. Both models can operate on either 12 or 24-volts DC.

Advantages: Simplicity of installation and operation
Moderate cost (approx. \$800)

Disadvantages: Must be rebuilt every 1 to 2 years if under continuous use - more often if water is not pure



The **surface piston pumps** have a suction capacity of 25 feet and are adaptable to shallow wells, springs, ponds, or streams. They can deliver water at the rate of 4.5 to 9 gpm with lift capability of approximately 150 feet. They operate on 12, 24, and 48-volts DC.

Advantages: Durable and easily rebuilt

Tolerant of dirty water.

Uses the least power per gallon delivered

Disadvantages: Only useful with shallow water sources

Moderately expensive (approx. \$1,400)

The **submersible piston pumps** like the surface type are very efficient power consumers and can be used in wells as deep as 600 feet. Their water delivery ranges from 1 to 7 gpm depending on lift and power supplied.

Advantages: Durable and adaptable to any water source

Uses the least power per gallon delivered

Disadvantages: Expensive (approx. \$1900)





The Slowpump (Vane) can lift water as high as 450 feet using 12 or 24-volts DC. The flow rate is between 0.5 gpm and 4 gpm depending on lift. Filtration is required to protect the pump.

Advantages: Relatively low cost (approx. \$500)
Operates on very low power

Disadvantages: Intolerant of impure water
Must replace filter regularly

The Simple Pump (sucker rod type) can lift water 480 feet at 0.5 gpm using a one-fifth horsepower DC motor. Its flow rate range is between 0.5 and 2 gpm yielding between 350 to 1500 gallons per day. It operates on 12-volts DC.

Advantages: Adaptable to wells

Disadvantages: Rods and piston can become unscrewed requiring removal and reinstallation of pipe
Low volume water delivery



The storage tanks were designed to be large enough to hold three or more days supply of water. They were typically located as high on a hill as possible in order

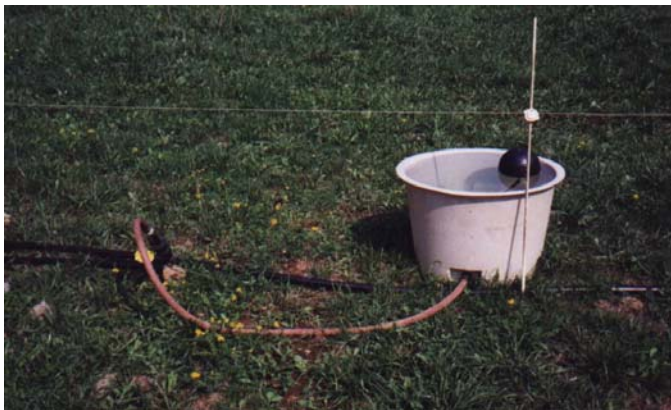


to pressurize the water supply lines that deliver water to the drinking troughs in the individual paddocks. Wherever possible we tried to locate storage tanks at least fifty feet in elevation above the upper most drinking troughs to achieve a minimum pressure of 20 pounds per square inch (PSI). The tanks could be buried for year-around use or be placed above ground in shady wooded areas to maintain cooler water temperature. The tanks were of various materials including concrete, stainless steel, and polyethylene. Materials that prevent sunlight penetration were the most effective for controlling algae growth in the stored water.

The **water supply lines** were laid between the storage tank and the pastures. Typically 1.0-inch to 1.25-inch rolled plastic water pipe was used as the main lines with hoses leading from quick-connect fittings installed on the water mains to portable rubberized drinking troughs in the individual paddocks. The quick-connect fittings provided numerous connection points and allowed easy movement of the drinking troughs between the paddocks. A few participants chose to bury their pipelines for year-round use while most just installed their pipelines about one foot underground to keep it cool and protected. These shallow installations must be installed on a constant grade to allow the line to be drained prior to winter and freezing conditions.



Two primary types of **livestock drinking troughs** were used for the project.



These were portable plastic tubs with float valves and precast concrete tanks. The portable tubs were connected to the pipeline using a quick connect fitting and a hose. The tubs, which are manufactured in various sizes, are relatively inexpensive and easy to move from one paddock to the next. They are the preferred type of drinking

trough for the pressurized gravity system that was installed on the larger grazing systems.

The precast concrete troughs were used where only one or two water access areas were provided. They typically were sized at 500 or more gallons and often served as both the storage tank and drinking trough. This, however, was not the recommended design because, as a few participants found, the solar pumps were not being efficiently utilized without a separate large storage tank. Once the drinking trough filled, the float switch would shut the pump off even though

the sun would still be shining, thus wasting prime solar hours. Later in the day, livestock would drink from the trough but it would not begin to recharge until the next day and often not until the livestock were rotated out of the paddock. On most Pennsylvania systems every daylight hour is needed to supply an adequate volume of water for the livestock. Therefore it is best to invest in a large storage tank and use smaller drinking troughs.



PROBLEMS ENCOUNTERED

The project encountered a few equipment-related problems. The most common problem was with the pump controllers, however, even this only occurred on five installations. Two installations each burned out two controllers. As a result we hired one of our supplier/installers to troubleshoot one of the installations and the other is pending. No specific installation errors were found, however it was concluded that a possible problem was the close proximity of the pump controller and its cutout switch wires to an electric fence. It is possible that the electrical field generated by an electric fence could be picked up by the controller itself (if close enough) or more likely by wires running along the fence from the controller to the float switch in the storage tank. This is likely the case since the third controller that was installed did not have the cutout switch wires connected and it continues to operate. It has been speculated by our supplier/installers that these wires to the cutout switches do increase the potential for system failure from lightning strikes. Therefore, they strongly recommend the use of shielded wire that is properly grounded to help prevent the wires from collecting stray voltage from lightning or nearby electrical fields.

A different type of controller failure occurred on a system utilizing a battery bank. It was determined that this failure was the result of insufficient solar power to charge the batteries. As a result the pump drew the stored power substantially below the required 12.5-volts with a resulting amperage increase that literally burned out the controller. The extended period of rainy overcast sky was the cause of the failure, however this could have been avoided by connecting a low voltage cutout switch. Additional solar panels could have also helped. This was a case where we had a complicated installation that was located a great distance from the supplier/installer who only designed and delivered the solar components. It needed but did not receive the personal attention of the professional installer who we assume would have realized, during installation, that it needed a low voltage cutout.

The only pump failures that we experienced were with the two sucker rod pumps. Each failed for different reasons. The motor burned out on one and the rods continually unscrewed themselves on the other. The motor burnout occurred after a proper break-in period with the pump set to operate on its maximum stroke. This could be a warranty problem that is being investigated. The other problem, although annoying and time consuming, was not as critical and could have been avoided by using a lock compound on the threads during installation. All the other pumps to date have operated without failure. Likewise, all the solar panels have operated flawlessly.

WHEN IS SOLAR THE RIGHT CHOICE?

Cost is the dominant factor to consider when deciding whether to use solar or more conventional energy sources to move water from where it is available to where it is needed. For this project, the typical solar water pumping system did not actually exceed \$5,000 although several participants provided a match that far exceeded this amount. These additional costs were primarily the result of extensive high-tensile fencing systems that were installed to support the intensive rotational grazing system – an expense that would have occurred whether the watering system was conventional or solar powered.

Using a diaphragm pump and a “least cost analysis for providing water” the break-even distance for installing a 230-volt AC powered pump system was determined to be 1,500 feet. That is to say that if the water source were less than 1,500 from an existing electric panel, AC power would be the most cost-effective choice. For greater distances the solar pump would be the better choice.

Another comparison can be made if an adequate water supply is available at the farmstead. In this case the break-even point would be determined using the cost of installed waterline from the buildings to the pasture plus possibly the cost of a conventional pump upgrade if needed. Since the pump and solar components in this project typically cost \$3,200, this would be the maximum cost that could be spent on a conventional system upgrade/extension. At two dollars per foot installed, 1.5-inch plastic waterline could be extended 1600 feet from an existing pressurized water source for the cost of a typical solar pumping system. If the distance and resulting cost would be greater then the solar powered system would be less expensive to install. The break-even distance would be significantly less if a pump or other system upgrade would be needed.

RECOMMENDATIONS

Pumps:

- ◆ Do not select a pump that has a maintenance requirement that exceeds your capability or willingness to maintain it. Periodic pump rebuilding and replacement of filters are essential to certain pumps.

- ◆ If you choose a pump that requires the use of a filter, be sure to locate the filter where it is easy to change.
- ◆ Use pump performance/capacity charts to select a pump that can provide the needed volume in the mid-range of its capabilities.
- ◆ Where finances allow, use a more durable time tested pump such as the piston pumps. These pumps use the least power per gallon of water delivered and could have served all of our project needs. They are available as both surface pumps and submersible pumps.

Storage tank:

- ◆ At a minimum, size the tank with a three-day reserve. To avoid the cost of electronic shutoff controls and the apparent pump controller failures caused by them, it is recommended to use a significantly larger storage tank – possibly large enough to hold the volume that the pump is capable of conveying during a five to seven day period. The cost avoidance, especially when using polyethylene storage tanks that are located several hundred feet away from the pump, will typically cover the increased cost of a larger storage tank plus provide the added benefit of a larger reservoir.
- ◆ If electronic shutoff controls are used then only use # 18 shielded wire for the connections.

Electrical:

- ◆ Use the wiring diagrams provided with each solar panel to match the required voltage for the selected pump.
- ◆ Use the proper size wire for the given wire length, system voltage, and pump amperage assuming no greater than 2.5% voltage loss. A handy calculator is found at http://www.mikeholt.com/volt_drop.html (several others are available online as well)
- ◆ Always use a voltmeter to test the circuit prior to connecting to a pump controller or to the pump.
- ◆ Be absolutely certain which wire lead is positive (+) and which is negative (-). This is critical when connecting to the pump controller. Reverse polarity will destroy the controller circuitry.

Solar Panel Support and Rack:

- ◆ Purchase the rack specifically designed for the given array. You may make your own, preferably from aluminum angle, but you should be sure that your design complies with the panel manufacturer's warranty requirements.
- ◆ Mount the rack on a properly sized pole to assure stability in the wind. If you are installing the panels to keep them above the livestock and to avoid fencing the area off, then a substantially larger diameter pole will be needed than is specified for the rack. It will need to be sized based on the length of the pole and wind load resulting from the surface area of the array.
- ◆ Although tracker type racks do allow the panels to capture more solar energy, they are relatively expensive and add to the complexity of the system – i.e. one more thing to malfunction. We prefer to invest in additional panels rather

than use trackers on our farm installations where maintenance may not be a first priority.

BENEFITS ACHIEVED

The benefits of utilizing solar powered livestock watering systems are primarily environmental protection or improvement benefits although there were instances during this project where certain installations significantly reduced labor related to hauling water during a drought and improved the efficiency of livestock grazing. Reduced fuel consumption



with its inherent environmental benefits can be calculated based on the fact that mechanical harvesting is not necessary when livestock are on pasture harvesting their own feed. If the forage being consumed by livestock needed to be removed mechanically it would require approximately 5.4 gallons of diesel fuel per acre per year based on three cuttings. Since 50 acres of forage is the typical amount needed for a 50-cow dairy farm, the annual fuel savings would be 270 gallons per year. This is in addition to the fuel saved by livestock spreading their own waste on the pasture rather than collecting it in the barn and then hauling it to the field. The typical 50-cow dairy herd would produce 33,000 cubic feet of waste of which at least 60% or approximately 20,000 cubic feet would be deposited in the field by livestock using an intensive rotational grazing system. This would reduce the hauling of approximately 100 loads of manure to the field resulting in an estimated fuel saving of an additional 30 gallons per year.



The practice of delivering water to the livestock rather than allowing them to help themselves at the water source also has the added benefit of significantly reduced pollution of the water source. Typically livestock congregate in and around their water source and deposit a large percentage of their waste in or near the water. In addition, they destroy the vegetation around the water source thus exposing the soil to erosion. Moving the water to

the paddocks via pipeline and then rotating the drinking areas along with the pastures eliminate these problems of water pollution and soil erosion.

There were several instances where the solar pumping installations saved both labor and fuel associated with hauling water to the livestock. At the onset of the project many parts of Pennsylvania were experiencing severe drought conditions.

Several of the project participants installed the solar pumps primarily to eliminate the need to haul water and reduce the demand on their primary domestic water source.

CONCLUSIONS

Solar power can be a viable alternative to conventional power sources for water pumping in remote areas if it is properly designed, installed, and maintained. Our first hand experience with these installations has convinced us that, for all except possibly the simplest systems, a professional solar component designer/installer should be hired - if only for the warranty benefits. Solar components are relatively expensive and as we found, the pump controllers are somewhat fragile. The professional should be able to avoid the problems that we encountered or at least provide a troubleshooting service under a warranty. The major drawback to this is the fact that there are so few qualified installers of solar water pump systems and components.

Our experiences with the assortment of pump types previously described has caused us to favor the piston pumps. Although they all can satisfy the requirements for particular circumstances, the piston pumps were found to be much more reliable and durable. They also were found to use the least amount of power per gallon of water delivered and are capable of delivering high enough volumes to satisfy the water requirements of a typical 50-cow dairy herd on pasture. There were no complaints about the piston pumps where as all the other pump types experienced problems with inadequate water delivery rate on several installations. The diaphragm pumps are our second choice because of the relative simplicity of installation and cost. Although they have a much higher maintenance requirement than piston pumps, there is a use for them where there is a very clean water source and a relatively low water requirement. Small beef operations of 25-head or less or sheep operations would find the diaphragm pumps to be very satisfactory.

Since we have been involved with this solar water-pumping project we have received numerous inquiries about the use of solar power on farms as well as other alternative energy sources. For most it has not been a search for an inexpensive power source and pump system but rather a dependable installation in a remote location. We have designed and installed a few of these systems as a direct result of individuals seeing or hearing about this project. We expect to continue to build on the success and experiences gained through this project for many years to come. We will be posting and documenting our progress on our web site at www.parc.org.