

**Solar Systems for Use in Agriculture**  
**With a Case Study: Livestock Water and Drip Irrigation**

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**Ing. Jaime Rochin Garces**  
**Agencia Estatal de FIRCO**  
**Baja California Sur**

**Abraham Ellis**  
**Southwest Technology Development Institute**  
**Las Cruces, New Mexico**

**John W. Strachan**  
**Sandia National Laboratories**  
**Albuquerque, New Mexico**

## **Executive Summary**

This article presents the concept of the sustainable ranch and the integral application of technologies to improve cattle ranch production. These technologies include a photovoltaic water pumping system, the use of man-made water retention ponds, drip irrigation for the production of fodder and in-situ silage of the same. The Agua Blanca Ranch located in the Mexican State of Baja California Sur is presented as a case study. This project was implemented in a collaborative effort of Mexico's Joint Risk Trust Fund (Fideicomiso de Riesgo Compartido) and Sandia National Laboratories for the purpose of promoting the use of renewable energy in Mexican agriculture.

## **1. Introduction**

In the period from 1993 to 1997, more than 100 photovoltaic (PV) water pumping systems were installed and put in operation to provide livestock water for Mexican cattle ranches. These pump systems consist of an array of PV modules, an electric pump, a pump controller, and the water storage and distribution system. The majority of them were installed in the Mexican states of Chihuahua, Sonora, Baja California Sur, and Quintana Roo. These projects were implemented through a program for renewable energy technology initiated by the Shared Risk Trust Fund (Spanish acronym: FIRCO) with the collaboration of various U.S. organizations under the direction of Sandia National Laboratories. The U.S. Department of Energy and the Mexican mission of the U.S. Agency for International Development (USAID) provided funding. FIRCO's engineers developed the projects and the specifications for the equipment and Mexican vendors installed the systems and placed them into operation.



Figure 1: Photovoltaic water pumping system at Rancho Agua Blanca, Baja California Sur, Mexico.

The purpose for contributing this article at the Symposium is to present the application of this technology in the desert region of Baja California Sur. At the beginning of 1998, a project was carried out in the Baja California ranch of Agua Blanca. The livestock well for this

ranch was equipped with a solar powered pump (Figure 1), and the ranch owner used the water both for livestock and for the production on a small section of land of forage for the cattle.

This article has the following organization:

Section 2: Photovoltaic systems technology. The section offers an introduction to photovoltaic (PV) power and systems which employ it.

Section 3: PV systems for water pumping – a brief explanation.

Section 4: The application of PV water pumping for livestock watering and drip irrigation.

Section 5: Conclusions

Section 6: References

Appendix A: A photographic essay of the pump and drip irrigation system at Rancho Agua Blanca.

The perspective we bring to this work is of field engineers who use renewable energy technologies and who, at the same time, examine and investigate their value economic viability.

The results we present support the following thesis: PV water pumping systems with hydraulic capacity in the range of 200 m<sup>4</sup> are technically viable and often the best economic choice when life-cycle cost is considered. Furthermore, users and project implementers should not overlook other benefits of solar water pumping such as its automatic operation, maintenance, and its environmental benefits. At the same time they should be

aware of those conditions under which these systems are not economically competitive - when grid electricity is available or when the cost of fuel and maintenance for a fossil-fuel powered pump are comparatively low.

We conclude, based on our observations of the emerging market in the cattle industry in northern Mexico, that PV pump systems for livestock water and drip irrigation will be increasingly competitive during the coming years. It is likely that the size of systems employed will be smaller than the case study presented in this paper due to the high capital cost of the equipment and the fact that Mexico's small cattle ranchers tend not to use financing.

## 2. Photovoltaic Technology and Photovoltaic Systems

Photovoltaic technology allows the conversion of photon energy in sunlight directly into electric energy, and this conversion is obtained through semiconductor materials.

**The photovoltaic effect**, which is observed in semiconductor material, begins with the release of electrons from the material under the impulse of photons. Adjacent layers of semiconductor material are designed to produce opposite polarities and the interface of these layers is designed to maintain that polarity and force the movement of the electrons from the negative layer to the positive layer through an external circuit, performing useful electric work. A photovoltaic cell produces a nominal voltage of ½ V and its electric current is a function of the surface area of the cell. A commercial **photovoltaic module** is manufactured by interconnecting PV cells in series and parallel groupings to produce the desired voltage and current characteristics. This arrangement of cells is sealed to form the module, which is the basic power unit used in PV systems.



Figure 2: This PV water pumping system was installed in 1994 in the rural community of Sirebampo, Sonora. It produces 5,000 liters of water per day from a hand dug well equipped with a submersible centrifugal pump powered by 8 PV modules (424 Watts).

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A PV system uses one or more PV modules, which are chosen and interconnected in order to provide the total power required by the load, with the desired voltage and current. The simplest stand-alone system<sup>1</sup> consists of an array of PV modules and the electric load. A battery can be used to enable operation of the load at night or during cloudy weather. To avoid excessive charging or discharging of the battery, these systems include a charge controller. When the load requires alternating current, the PV system includes an inverter. PV arrays are mounted on either fixed array structures or on a tracker which enables the array to follow the sun's movement and thereby capture more of the sun's energy.

Photovoltaic technology is in its third decade of commercial terrestrial application. In 25 years, it has experienced rapid development and, primarily because of the reduction in the cost of PV modules, has been established as a viable alternative with a range of applications. Engineers who use PV systems characterize them as having high reliability and modularity for design, low O&M costs, minimal environmental impact and long useful lives.

The typical market for PV systems is for applications, which require

- *generation of modest quantities of electric power*
- *in remote locations that are difficult to access and that are without conventional (grid-supplied) electricity.*

The principle categories of terrestrial PV applications are telecommunications, bi-directional radio, rural telephone, rural domestic and public electrification, cathodic protection, maritime applications, and, in the rural environment, telephone and public illumination. In agriculture, water pumping, electric fences and electric dairy milking are applications with a growing visibility.

PV energy is used extensively at remote repeater stations for communication (radio, television and telephony); the size and type of these systems vary with the electric power needs. A 100 Watt PV module with a controller and battery is sufficient for a rural telephone or radio while repeater stations for radio and television use PV arrays of 5 to 50 kW, these being typically large hybrid systems with power storage, a control system, and a backup, fuel-powered generator.

PV systems for rural electrification are divided into two classes: home systems and village power systems. Home lighting systems are perhaps the most common PV systems worldwide[1]. These systems use direct current and are made up of one or more PV modules, a charge controller, and a battery. They provide electricity for 3 to 5 hours a day for fluorescent lights and various low-power electric appliances such as a black & white television or a radio. Today there are more than 150,000 such systems installed worldwide.

Community power systems can have a multiple-kilowatt capacity and are frequently hybrid systems, which include other power sources such as wind generators, and a fuel-powered generator which serves as a backup to increase system reliability.

PV systems for agricultural use include water pumping, electric fences and milking systems. Water pumping for agriculture is an attractive application given the natural coupling between water demand and available solar energy, i.e. it is typical that the solar resource is best when water is in greatest demand.

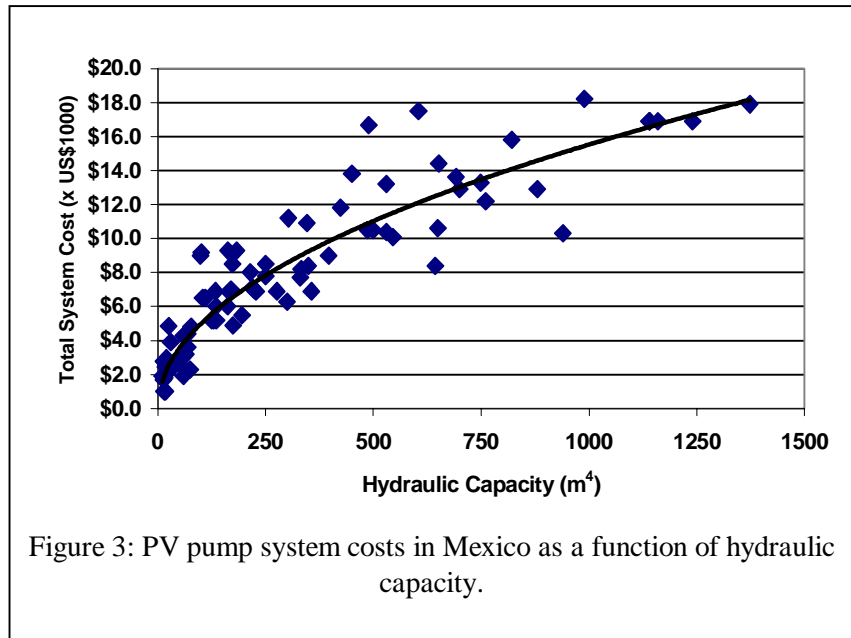
An electric fence requires small quantities of electric power such that 20 Watt PV modules are adequate to maintain the system's battery.

Other applications include monitoring stations and maritime signals, cathodic protection, vaccine refrigeration and small-scale industrial processes. In addition, the use of PV systems in ecotourism and the management of protected areas has grown during recent years because of the low environmental impact of this technology.

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<sup>1</sup> For this discussion we are setting aside PV systems interconnected to central electric grids.

Presently the initial cost of PV systems continues to be high compared to traditional alternatives such as fuel-powered generators. However, in many cases, particularly in remote locations, the initial capital investment is economically justified by the savings in and the lower O&M costs as well as the increased reliability and the longer expected useful life of the PV systems. A comparison of the life cycle cost of PV the traditional fuel-powered alternative demonstrates that the total cost, including not just the initial capital cost, but the O&M costs over the life of the systems, is greater for fuel-powered generators than for PV systems in many remote locations. Nonetheless, the initial higher capital of PV systems represents a barrier because of the lack of financing or other mechanisms to enable that initial investment.



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### 3. PV Systems for Water Pumping

The cost of the PV water pumping systems installed as part of the joint program between FIRCO and Sandia National Laboratories between 1995 and 1997 are shown in Figure 3. The costs are shown as a function of the hydraulic capacity of each system<sup>2</sup>, and include the cost of the equipment, its installation, the vendor and manufacturer guarantees and the Mexican value-added tax.

The initial higher capital cost of these systems suggests the need for an economic analysis, which we present in the case study further on. In advance of that, it can be said that in general, PV water pumping systems are the economically preferable choice in an off-grid setting only when the operation of a fuel-powered pump proves to be more expensive because of

- the high cost or difficulty of obtaining a reliable supply of fuel, and/or
- the high cost of operation and maintenance of the fuel-powered pump system and/or difficulty in obtaining reliable service.

The experience of the joint FIRCO / Sandia program has been that these conditions are met

	PV Pump System	Fuel-Powered Pump System
Initial capital cost:	high	low
Fuel:	solar energy (no cost)	gas/diesel (high cost)
Operation:	automatic (no labor)	manual (involves labor cost)
Maintenance:		
motor	low (electric motor)	high
pump	low	low
PV module	low (periodic cleaning)	not applicable
controller	no	not applicable
Useful life of components:		
PV module	20 years, or more	not applicable
controller	4-8 years	not applicable
pump/motor set	4-12 years	2-4 years

<sup>2</sup> Hydraulic capacity (measured in m<sup>4</sup>, is the product of the total dynamic head (in meters) and the daily capacity of the pump system (in cubic meters/day).

with frequency in locations that Generally a PV pump system maintenance than a fuel-qualitative comparison between The components of a PV water modules, its support structure, motor set. Also included is the system. The **PV array** is sized voltage required by the pump.

Two types of PV array which is generally set on a structure (Figure 4), which is the PV array oriented toward can increase water production

The function of the **controller** is adjusting the voltage supplied to motors have been AC motors inverters within the controller. available for PV applications, Under conditions of low reduces the voltage and which enables the pump to albeit at a reduced rate.

The **pumps** typically used in PV pump systems include centrifugal submersible pumps (see example in Figure 5), diaphragm pumps, jack pumps, surface centrifugal, and piston pumps.

#### 4. Case Study: Rancho Agua Blanca

Because of its geographic location and conditions, the State of Baja California Sur presents difficult conditions for sustainable cattle ranching. This is a semi-desert climate with an annual average temperature of 22° C and an annual average rainfall 180 mm. Precipitation is rare in this region and is generally associated with hurricanes or tropical storms which produce intense, short-duration rainfall.

Beginning in 1995 the state agency for FIRCO in Baja California Sur proposed, within the framework of the Alianza para el Campo Program, the implementation of strategy to enable the sustainable development of cattle ranching. This strategy favored the substitution of conventional energy with renewable energy for the development of productive agricultural activities and complementary activities.

The concept of the sustainable ranch is a response to the difficult conditions which ranchers of the region face. These conditions include:

- difficult and costly supply of water and fodder for cattle,
- shortage of water and fodder during the dry season,
- the lack of ranching infrastructure,
- high production costs,
- loss of livestock during times of draught,
- deforestation, primarily of native foraging species, which are used for fuel wood,
- over-exploitation of the range and



Figure 4: **The tracker** is a pole-mounted mechanism that supports the PV array structure designed to maintain the array tilted toward the sun, thus maximizing the solar energy captured by the array and converted to electricity. It can increase water production by 20 to 30%.

are remote or difficult to access.

operates automatically and requires less powered pump system. Table 1 offers a the two options.

pumping system include the PV array of the system controller, and the pump / water storage and water distribution to provide the total power at the desired

**structures** are used: 1) a fixed structure, cement footing and 2) a tracking support mounted on a pole and which maintains the sun throughout the entire day. Its use by 20 to 30%.

to optimize the production of water by the pump **motor**. Historically pump whose use required the incorporation of Recently DC motors have become eliminating the need for this component. insolation, the pump system controller increases the current to the pump motor continue operating and producing water,



Fig. 5: Submersible centrifugal pump

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- low productivity and abandonment of ranches.

The concept of the sustainable cattle ranch, illustrated in Figure 6, is one of the integral development and exploitation of natural resources, the use of alternative energy for water pumping, the grinding of fodder, and for electric fences. It includes as well the development of water retention ponds to capture rainwater and the development of the ranch infrastructure. Finally, it incorporates drip irrigation for the production of fodder and low-cost silage for its storage.

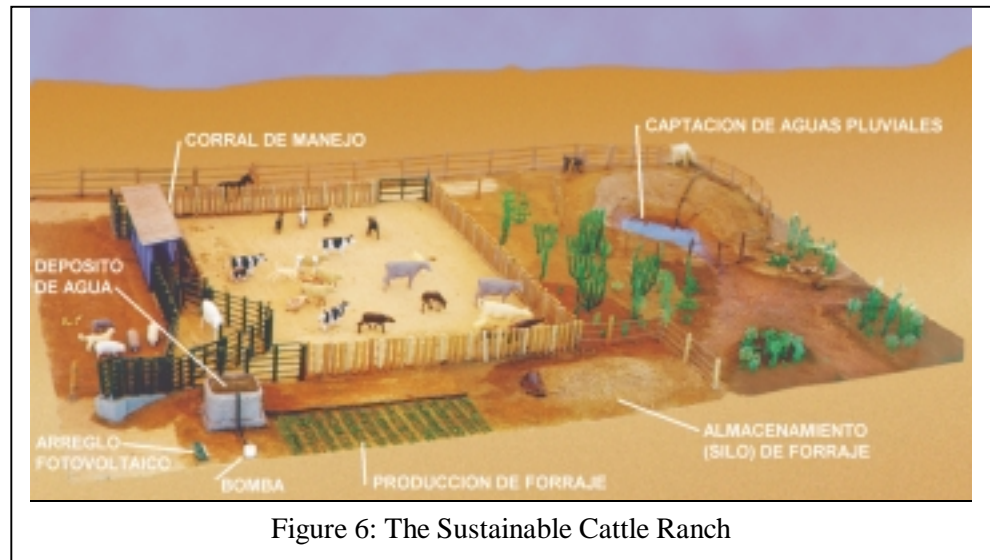


Figure 6: The Sustainable Cattle Ranch

The case study of Rancho Agua Blanca is presented below as a real example of the implementation, starting in 1998, of this concept. Appendix A provides photographs of the PV pumping and drip irrigation system at the ranch.

#### **4.1 Background on Rancho Agua Blanca**

Rancho Agua Blanca is located 120 km north of La Paz. The ranch has 39 head of cattle and covers 1011 hectares of land, 25 of which are cultivated buffalo grass pasture land with water retention ponds. There are 3 hectares of arable land, 983 hectares of natural (desert) pasture, two wells, a corral for 70 head of cattle, 8 km of fencing and 1 km of fence divisions. There is a ratio of 40 hectares per head of cattle.

The Rancho Agua Blanca project had the following goals:

- increase productivity,
- produce and store (in low-cost silos) 120 tons per year of forage,
- increase meat production by 4 tons per year and the production of cheese by 0.65 tons, and
- reduce production costs by 18%.

Given these objectives, the following investments were made:

1. Equipping of a well with a PV water pumping system capable of providing 25,000 liters/day.
2. Construction of a 35,000 liter water storage tank.
3. Excavation of water retaining ponds to capture rainwater run-off.
4. Installation of a drip-irrigation system for the production of sorghum.
5. Development of 25 new hectares of buffalo pasture land.
6. Acquisition of 10 calves.

#### **PV Pump Equipment**

The specifications for the PV pump system included the following:

- daily water demand: 25,000 liters
- total dynamic head (based on well characteristics & system design): 25 meters
- average daily available insolation (horizontal surface): 5.56 kWh/m<sup>2</sup>-day

The PV system equipment selected is listed in the Table 2. Total PV system cost was 84,544 pesos.

#### **Drip Irrigation System**

Agua Blanca had available 3 hectares for cultivation. The soil was characterized as 38% sand, 55% lime, and 7% clay. With a cost of 10,110 pesos, a drip irrigation system was installed.

Table 2: PV Pump Equipment for Agua Blanca											
Quantity	Description										
1	Submersible centrifugal pump, stainless steel, Solarjack SCS 14-160, 1 HP										
10	PV modules, Kyocera, KC80, 80 Watts (each) (5 modules in series & 2 in parallel)										
1	Controller, Solarjack de 1200 Watts										
1	Flow meter, Delaunet, 2" diameter discharge										
1	Balance of system components:										
	<table border="1"> <tbody> <tr> <td>Module support structure</td> <td>Module fasteners</td> </tr> <tr> <td>Disconnect switch</td> <td>Grounding wires for modules</td> </tr> <tr> <td>Fuses</td> <td>PVC piping</td> </tr> <tr> <td>Wiring</td> <td>Pump support</td> </tr> <tr> <td>Lightning ground rod</td> <td></td> </tr> </tbody> </table>	Module support structure	Module fasteners	Disconnect switch	Grounding wires for modules	Fuses	PVC piping	Wiring	Pump support	Lightning ground rod	
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Wiring	Pump support										
Lightning ground rod											

## 5. Results & Conclusions

The project to develop sustainable ranches in Baja California Sur provides an example of the use of renewable energy together with simple techniques for drip irrigation and the capture of rain water. Photovoltaic water pumping offers several advantages: fewer costs for operation and maintenance because of the automatic operation of the system without the use of costly fossil fuel. The use of solar energy also results in reduction of greenhouse gasses and avoids local pollution of the air, soil and of the well itself. The capture and utilization of rainwater to develop and improve pastureland is a simple, low-cost measure that maximizes the use of this resource. Likewise, the rational use of water for limited production of forage and the storage of this in silos helps keep the ranch operation viable during periods of draught and crisis

The investments described here in Rancho Agua Blanca were made at the beginning of 1998, and the evaluation of this project is still in its preliminary phase. Results to date suggest that the project is viable and will show an annual return on investment of 380,500 pesos, a benefit/cost ratio of 2.9, and a rate of return on investment of more than 19%. The substitution of PV pumping for fuel-powered pumping is expected to prove economically favorable and facilitate the solution of the problem (greatly reduce the cash outlay) of providing fodder to the herd during the annual draught. It may also facilitate rational use of resources and help realize the goal of the *Alianza para el Campo* program to increase the production of meat and cheese.

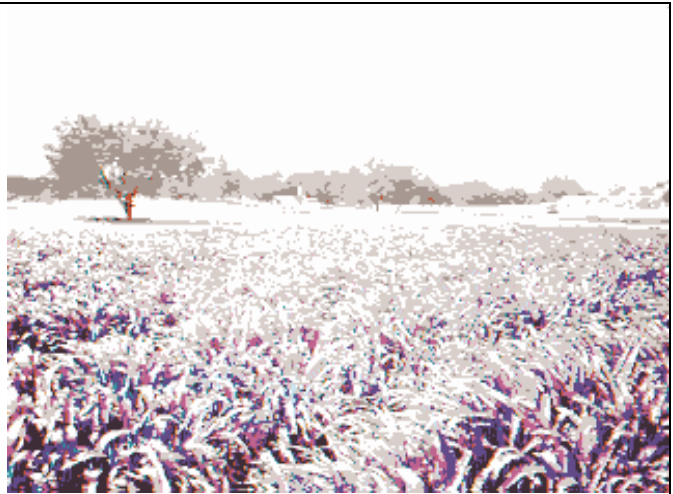
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4. "Water Pumping, The Solar Alternative", Michael G. Thomas, Sandia National Laboratories, Albuquerque, New Mexico, SANDIA Report #87-0804, 1989.
5. "A Ten Year Review of Performance of Photovoltaic Systems," 23<sup>rd</sup> IEEE Photovoltaic Specialists conference, May 1993, pp. 1289-1291.

## Appendix A: Photographic Essay



Rancho Agua Blanca: Equipo de bombeo con energía solar.



Rancho Agua Blanca: Producción intensiva de forraje.



Obras de captación y retención de escurrimientos pluviales.



Labores de cosecha de agua, para incrementar la producción forrajera en praderas inducidas de temporal.



Sistema de riego y uso de tecnología intermedia, sembradora manual de precisión.



Preparación del terreno con un motocultor, aprovechamiento de la tecnología intermedia.