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LIFE-CYCLE COST ANALYSIS FOR PHOTOVOLTAIC WATER PUMPING SYSTEMS IN MEXICO

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ABSTRACT

Sandia National Laboratories National Laboratories (SNL) and the Southwest Technology Development Institute (SWTDI) at New Mexico State University have been working in Mexico with a variety of program partners in developing sustainable markets for PV water pumping systems through the implementation of pilot projects. The program is sponsored by the U.S. Department of Energy (USDOE) and the U.S. Agency for International Development (USAID). In the area of water pumping, the tremendous rural demand for water represents a potential renewable market of over $500 million in Mexico. Through the SNL program, more than 130 photovoltaic water pumping projects have been installed in 8 Mexican states, most in partnership with the Mexican Trust for Shared Risk (FIRCO) or the Chihuahuan Renewable Energy Working Group. This program has provided a wide database of information related to system costs that have been used to provide life-cycle cost analysis determining the competitiveness of PV technologies for water pumping as compared to traditional technologies.

1. BACKGROUND

Mexico is a growing market for the use of renewable energy technologies. Over 5 million Mexicans do not have access to grid electricity in over 88,000 villages, while more than 100,000 rural communities are in need of potable drinking water. There are over 600,000 rural ranches in need of water for livestock and/or irrigation.

Life cycle cost (LCC) analysis is a useful tool that allows for an equal and useful comparison of solar and conventional water pumping technologies. Using this methodology, not just the initial costs, but all the future costs (operation and maintenance, replacements, transportation, and fuel) can yield a comprehensive and comparative view of total system costs over the life of the system. From the database of over 100 Mexican systems, LCC analysis were made for three different water-pumping systems in Mexico (small, average, and big scale).

A summary of the database of the first 105 PV water pumping systems shows the system combinations; comparative analysis of systems cost based on systems size and hydraulic duty; and all performance and maintenance requirements for these systems from 1994-1997. PV water pumping systems are highly competitive with conventional water pumping energy sources for array sizes from 2kW or less when compared on a life cycle cost basis. PV systems cost decrease significantly on a per Watt basis as PV system size is increased. When selecting PV water pumping systems, a wide variety of pump sizes and types are available, with a large viability found in pump life based on pump type. Life cycle costs are impacted by the type of pump selected. PV water pumping is one of the most cost-competitive applications for PV technologies today.

2. PROGRAM RESULTS

Since the inception of the SNL Mexico renewable energy program in 1994, more than 180 renewable energy systems, representing more than 100 kWp, have been installed to provide energy for more than 9000 rural Mexicans in 8 states. Approximately 130 of these installations have been for water pumping applications and more than 50 are for electrification, communications, and other applications. Figure 1 shows the overall renewable capacity (kWp) that have been installed since the inception of the program. While the majority of these projects have utilized photovoltaic energy, the program is demonstrating wind energy in several applications including water pumping, facilities power for hotels and visitor centers at reserves, and centralized community hybrid systems. Project costs have been covered by contributions from SNL, the local counterpart agencies, and end users, with the SNL/USAID contributions typically averaging less than 50% of the project costs. These initial pilot projects have served as a base from which additional replication has been strongly seen.

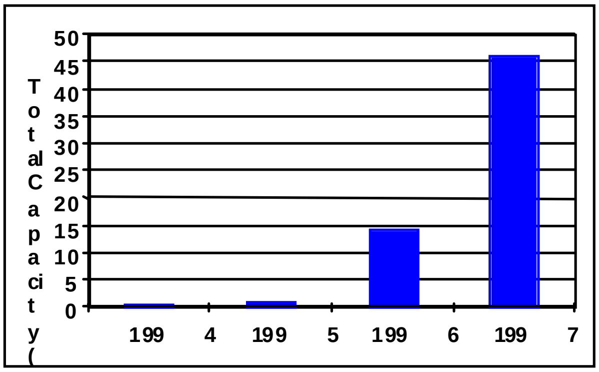

Figure 1. SNL Mexico Program installed renewable energy capacity per year.

As a result of program activities, more suppliers are providing better systems at generally lower prices than before this program was initiated. In Chihuahua, for example, where program activities were initiated in 1994, the number of highly competent renewable energy equipment suppliers has grown from 4 to 10. In total, more than 25 local system suppliers throughout Mexico have participated in the program. These industry growth trends and increasing competition have helped to lower overall installed system costs, while quality levels have improved substantially. For instance, installed costs of PV water pumping systems have decreased as vendors and program administrators gain experience with technologies; this despite the fact that PV module prices have not fallen over the same time frame. Figure 2 illustrates this trend, showing the decrease in costs for water pumping systems purchased program-wide. Figure 2 also shows examples for the states of Chihuahua and Baja California Sur, where the program has had very positive results over the last 2 to 4 years. Note that these costs include all system hardware (pumps, conductors, etc.), as well as labor and taxes. Many of these same vendors also have expanded their service territories to other states, further contributing to increased competition and decreasing system costs nationwide.

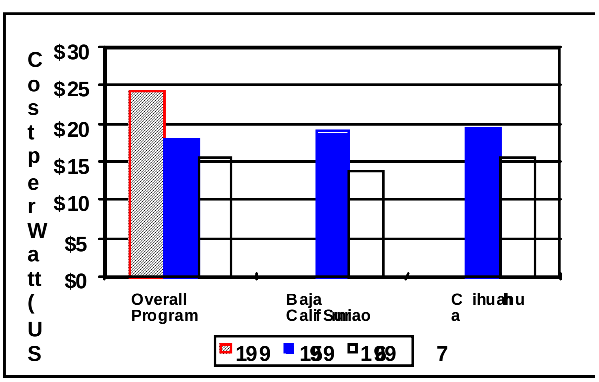

Figure 2. SNL Mexico Program PV water pumping systems average cost per Watt.

The SNL team maintains a continually updated database on technical, economic, social, and environmental aspects of the installed renewable systems. Using the information in this database, project developers can determine the appropriateness of renewable energy technologies to meet their future needs, and industry members can assess the performance of their fielded systems, thus providing valuable feedback for technology improvements. SNL can also assess the effectiveness of program activities by analyzing the information in the database. Table 1 shows summary maintenance information in the database as of October, 1997.

Table 1. SNL Mexico Program Maintenance Actions

Type of Maintenance	No. of Occurrences
Emergency	1
Planned maintenance	8
Unplanned maintenance	7
No maintenance activity	56

The SNL program is utilizing information maintained in the database to determine the economic benefits of the types of systems installed through the program. Below are the general assumptions used for life-cycle cost (LCC) analysis of water pumping systems in Mexico.

Assumptions - LCC Analysis

Economic Parameters

Discount Rate:	18%/yr
Fuel Inflation Rate:	24%/yr
Inflation:	12%/yr
Differential Fuel Inflation:	12%/yr
Real Discount Rate:	6%/yr

PV System	Conventional System
Replacements	
Pump Grundfos: 20 years	Generator: 13 years
Pump Shurflo: 10 years	Pump: 6 years
Operation and Maintenance	
1% initial capital cost	$200 per year
Transportation to Site	
144 visits/year	365 visits/year
4 liters/visit (round-trip)	4 liters/visit (round-trip)
$0.41/liter gasoline	$0.41/liter gasoline
Fuel Costs	
None	Small System: 400 l/yr
	Average System: 1,500 l/yr
	Big System: 2,800 l/yr.

Figure 3. PV pump at Rancho Jeromin in Chihuahua.

AVERAGE SYSTEM

Rancho Jeromin in Chihuahua, installed in March 1997, is a good example of an average size PV water pumping system in Mexico. The system has 848 Wp of PV powering a submersible centrifugal AC Grundfos water pump via an inverter/controller. Figures 4 is an example of the output of LCC analysis of this system. In this case, the PV system replaced a diesel generator, so real data was available regarding the comparative costs of using diesel versus PV. In Figure 5, in spite of higher initial costs, after 2.5 years, the PV system investment is recuperated.

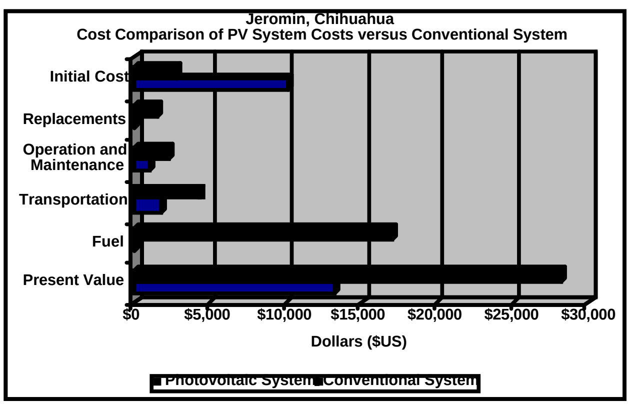

Figure 4. Life-cycle costs of Jeromin PV vs. diesel pump

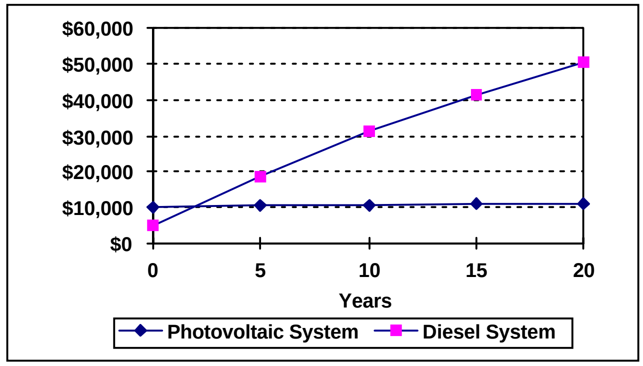

Figure 5. Payback point for Rancho Jeromin vs. Diesel at about 2.5 years.

SMALL SYSTEM

Many PV water pumping systems installed in Mexico are small, often only 100-200 Wp. Figure 6 below shows the installation of a 106 Wp PV water pumping system at Buena Vista in Chihuahua in September, 1994. The system pumps about 3.5 m3 of water a day at 15m head using a 12 V DC submersible diaghram Shurflo pump.

Figure 6. Buena Vista PV pump in Meoqui, Chihuahua.

Figures 7 shows the output of the LCC analysis of this system. In this case, the PV system replaced a gasoline powered pump. In Figure 8, in spite of higher initial costs, after 2 years, the PV system investment is fully recuperated.

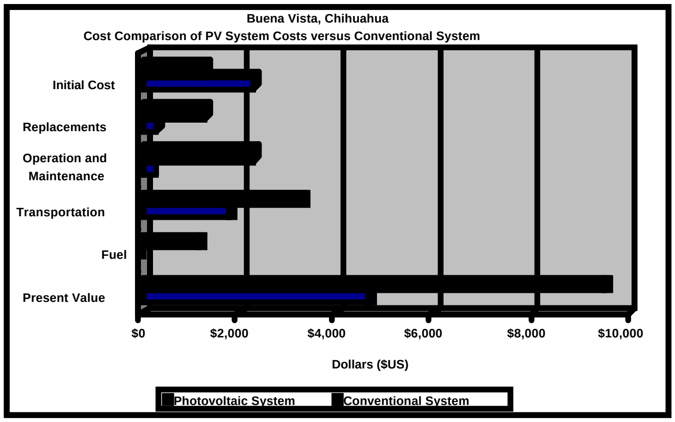

Figure 7. LCC costs comparison for Buena Vista.

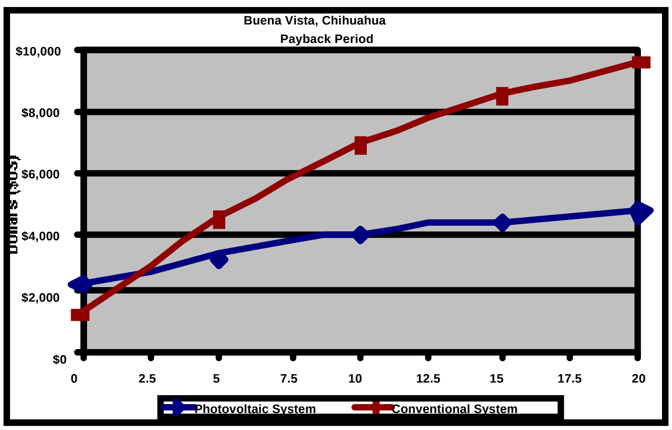

Figure 8. Two year payback for Buena Vista PV system.

LARGE SYSTEM

In August 1997, the SNL program installed a good example of a larger PV water pumping system in El Reventon, San Luis Potosí as shown in Figure 9. This system pumps over 17 m3 of water per day at a total dynamic head of 58 m. Previously, the system was pumped by a horse and the ranchers had to evaluate whether to go with a conventional gasoline powered water- pumping system or with a PV system. They opted for PV and a 1530 Wp array is used to power an AC Grundfos submersible pump via a Solartronic inverter/controller.

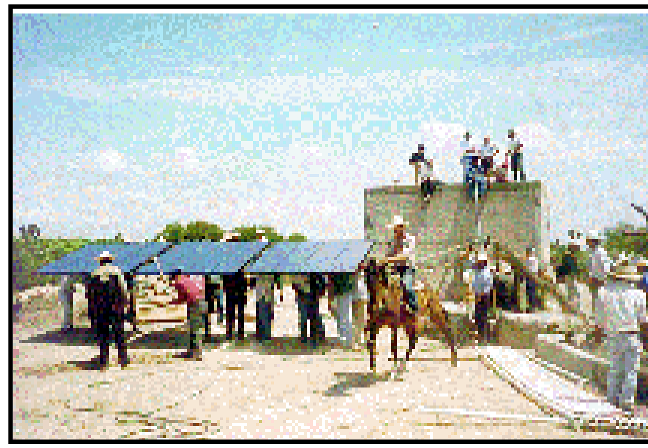

Figure 9. El Reventon PV pumper in San Luis Potosí

The payback for this type of system is much longer based on an LCC analysis than for the smaller systems. Figure 10 shows the output of the LCC analysis of this system. In this case, the PV system is compared to a traditional gasoline powered pump. In Figure 11, the PV system investment is fully recuperated after about 15 years. This type of reliable AC pump and PV system should be able to last this long or longer. In general, PV water pumping systems rarely exceed about 2 kW in size as this represent the approximate maximum payback in conventional economic terms.

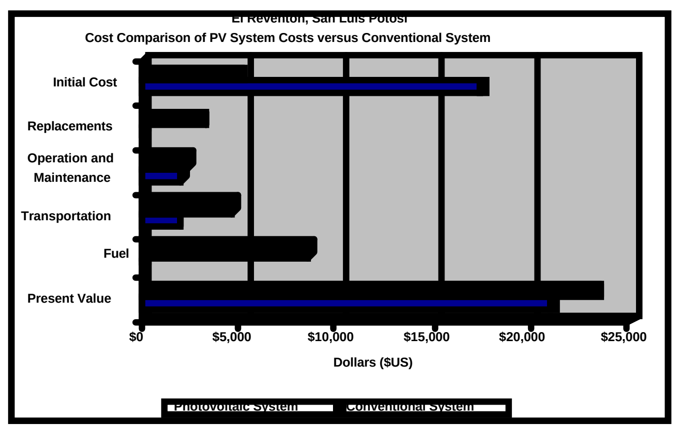

Figure 10: El Reventon LCC Analysis.

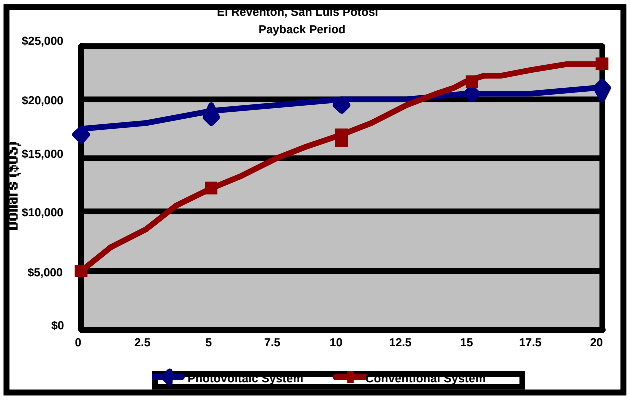

Figure 11. El Reventon payback is 15 years.

4. GENERAL PROGRAM STATISTICS

Through the SNL program, more than 120 photovoltaic water pumping projects have been installed in 8 Mexican states, most in partnership with the Mexican Trust for Shared Risk (FIRCO) or the Chihuahuan Renewable Energy Working Group. Working with FIRCO, the SNL Mexico program has successfully negotiated the inclusion of renewable energy technologies in the Alliance for the Countryside (Alianza Para el Campo) program. More than 50 pilot PV water pumping projects under the Alianza program have been installed in Mexico thus far, and several hundred more have been identified. A sampling of the first 105 PV water pumping installations is shown in Figures 12 and 13, which show the costs of PV system on a peak Watt and a hydraulic duty (m4: volume times total dynamic head) basis.

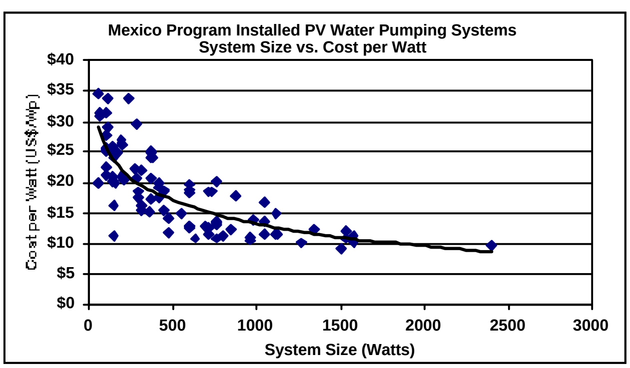

Figure 12. Costs for 105 Systems based on size (Wp).

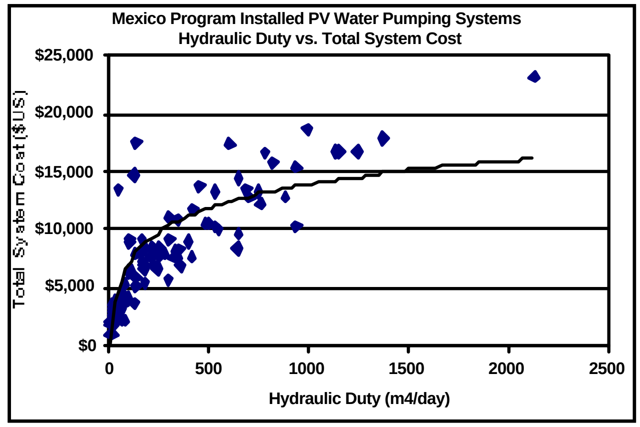

Figure 13. System costs based on hydraulic duty (m4).

5. CONCLUSIONS

Life-cycle cost analysis based on data from the first 105 installations in this program compares PV versus conventional gasoline or diesel water pumping technologies. PV systems are generally competitive for water pumping applications to about 2 kW in size, or for about 1,500 m4 of total hydraulic duty. Additional benefits (i.e. externalities) such as the elimination of potential well contamination and health risks from hydrocarbon fuels are not included here and are difficult to reflect in conventional LCC economic analysis.

Through increasing the visibility of renewable energy technologies in Mexico and demonstrating the benefits to rural users, the SNL program is producing results that provide evidence of sustainable, growing markets in several regions of the country. The increased visibility brought on by program installations has led to stronger competition, lower prices, higher quality, and significant growth in the number of new systems installed. PV water pumping technologies are gradually gaining a competitive foothold in Mexico and changing the face of water pumping throughout rural Mexico.