Solar World Congress, International Solar Energy Society
Orlando, Florida, August 11, 2005

TWO DECADES OF PV LESSONS LEARNED IN LATIN AMERICA

Robert E. Foster
New Mexico State University
MSC 3 SOLAR, P.O. Box 30001
Las Cruces, New Mexico, 88003-8001 USA
rfoster@nmsu.edu

Alma D. Cota Espericueta
Universidad Autónoma de Cd. Juárez
Anillo Envolvente del Pronaf y Calle Estocolmo
Ciudad Juárez, Chihuahua, México
acota@uacj.mx

ABSTRACT

Over the past two decades, Latin America has adopted photovoltaic (PV) technologies for social and economic development. Many of the world's first solar systems for residential power, refrigeration, distance education, hybrid systems, etc. were developed for Latin America. This paper looks at how PV technology has been developed and used, including some successes and failures over the past 20 years.

1. INTRODUCTION

The use of PV systems in rural regions of Latin America has increased dramatically from an initial concept pioneered by a few visionaries over twenty years ago to many thriving businesses throughout the region. PV is a viable alternative to traditional large-scale rural grid systems. With the advent of PV as a dependable modern technology alternative and more private participation and choices made available to the general public, PV systems have become attractive all over Latin America with hundreds of thousands of rural households electrified via solar energy in this region. Rural undeveloped areas of Latin America represent a "natural" market for PV technologies. The challenge is to develop financing strategies that are affordable to potential clients.

2. PV HOME SYSTEMS

During the early 1980s, solar energy pioneers began to disseminate PV technologies in rural Latin America as a solution for providing basic electricity services for non-electrified populations. Some of the first pilot projects in Latin America were undertaken by NGOs, such Enersol Associates in the Dominican Republic beginning in 1984. Gradually throughout Latin America, small solar companies began to form in the late eighties as key module manufacturers at the time such as Solarex, Arco, etc., sought out distributors for off-grid rural markets. By the mid-1990s, these activities were followed by large scale solar electrification activities sponsored by government agencies in Mexico, Brazil, Colombia, Bolivia, Peru, etc. Many of these early large-scale PV government electrification efforts faced sustainability issues as planners attempted to force large scale rural solar electrification projects onto unknowledgeable rural users. Common problems faced included use of inappropriate battery technologies, substandard charge controllers, unscrupulous sales personnel, and poor quality installations. Despite these hurdles, only rarely did PV modules fail and they were generally the most reliable part of any installed system.

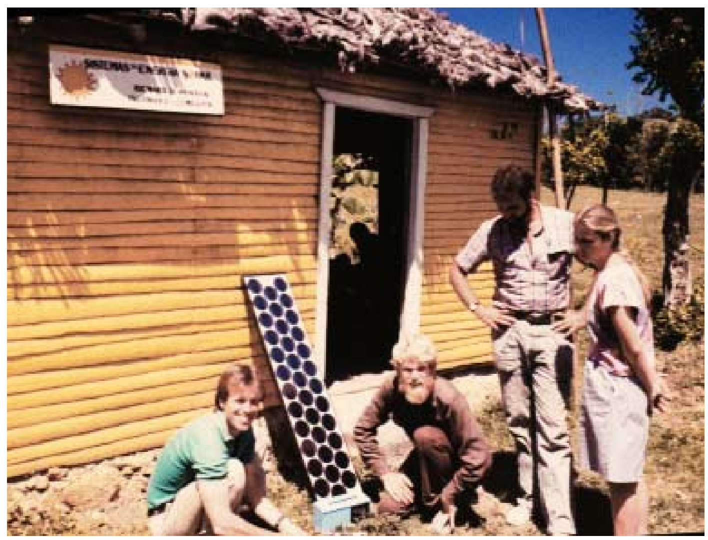


Fig. 1: Latin America's first PV training center established by Rich Hansen (far left) of Enersol Associates in the Dominican Republic, training both local technicians and Peace Corps volunteers (1985).

For instance in Mexico, there were large scale government PV rural electrification projects undertaken under PRONASOL in the early to mid-1990s with over 40,000 PV systems installed, especially in southern Mexico (e.g., Chiapas >12,000 systems). The government also dabbled in village scale PV and wind electrification. Unfortunately, over two thirds of these systems ceased functioning in only a couple of years. The era of large PV electrification projects in Mexico essentially came to a temporary halt by the late 1990s, in large part due to the poor performance and image of these original substandard PV systems. Typical problems were not related to the PV modules installed, but rather due

to balance of systems problems, in particular short battery life and shunt charge controller failures.
In Central America, large scale implementation of PV projects began in earnest during the mid-1990s and continue today. As in most places, PV first served remote communication systems. PV then began to be considered to meet basic domestic electricity needs. The first Central America PV and wind workshop was held in Guatemala in 1992 by Sandia National Labs and New Mexico State Univeristy (NMSU). Early capacity building tended to focus on PV technology and applications and creating a knowledgeable engineering base in country. Many of these engineers and planners would later be responsible for implementing the first PV electrification projects, such as the 1993 EEGSA project in the community of San Buenaventura, Guatemala for 68 homes using 50Wp systems costing US$620 each. Likewise, the founding of Guatemala's Fundación Solar in 1993 furthered progress, directly implementing over 3,000 PV electrification installations, mostly in the Quiché and Verapaz regions.

In response to early system failures, implementing agencies gradually began to adopt more rigid technical specifications that observed international standards that improved the quality and reliability of PV systems. Some examples include the current Comision Nacional de Energía/World Bank Programa de Electrificación Rural in Nicaragua for 6,000 homes, and the World Bank in Bolivia for 10,000 homes. Another example installed in 1999 was for 145 innovative PV home lighting systems installed by the State of Chihuahua as part of the USAID/DOE Mexican Renewable Energy Program (MREP) managed by Sandia National Labs. The intent of the Chihuahua pilot project was to demonstrate that simple PV lighting systems could be designed to provide reliable, essentially maintenance free electrical service for many years with full cost recovery. After six years of operation, over 90 percent of Solisto PV home lighting systems are performing well.

The Solisto PV systems were installed by Energía Solar de Cd. Juárez (ENSO) and designed by Sunwize Technologies to meet NMSU specifications based on the Mexican electric code. This is a prepackaged control unit engineered for small scale rural electrification and long life. The Moris systems consist of one 50 Wp Siemens PV module, which charges a nominal 12 V sealed absorbed glass matte battery (Concorde Sun-Xtender, 105 Ah) using a Steca charge controller.

NMSU found that 94 percent of users expressed complete satisfaction with their PV lighting systems, 86 percent thought that PV was better than their previous gas lighting source, and 62 percent believed that the PV systems were reasonably priced for the service provided. New and expanded evening activities were also reported such as sewing, TV, reading, and studying. After five years, the PV systems have saved about US$300 in lieu of previous gas and dry cell battery options, while providing superior light and entertainment capabilities. Systems were financed and users provided a 33% downpayment [1].

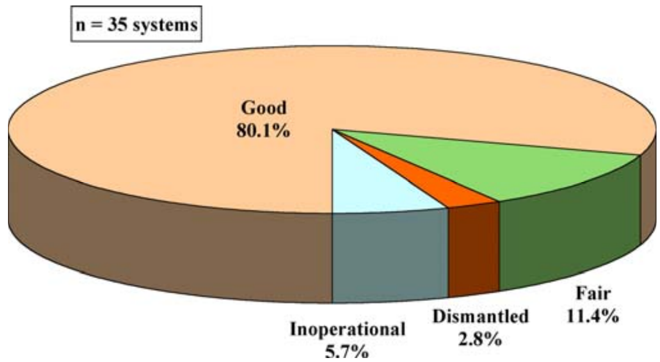


Fig. 2: Operational status of Solisto PV home systems in Chihuahua, Mexico after five years.

Other financing and leasing programs have been initiated in Nicaragua, Bolivia, Dominican Republic, Honduras, etc. by such organizations as the World Bank and companies like Soluz. These program have had mixed results and generally PV systems leasing has not been successful in part due to rural seasonal incomes. Rural Latin households pay anywhere from US$5-25/month for dry cell batteries and kerosene lighting, the main energy source PV competes against. Rural users mostly want a PV system for electric light and entertainment with radio and TV. PV financing programs can be set up in rural Latin America to compete with conventional technologies so long as financing terms are compatible with current rural user expenses and seasonal incomes.

Table 1. Changing the Focus of PV Projects

From Previous PV Projects that	To New PV Programs that
Only installed PV systems;	Promote development using PV Systems;
Provided donations and "gift" mentality;	Require buy-in and bilateral responsibilities;
Focused on men in rural areas;	Expand gender focus for both men and women;
Short term outlook;	10-20 year timeframes;
Worked with men that understand electricity and speak Spanish or Portuguese.	Work with women and men who have limited education and belong to different ethnic groups, cultures, and dialects.

3. PV ICE-MAKING AND REFRIGERATION

The world's first automatic commercial PV ice-making system was installed in March 1999 to serve the inland fishing community of Chorreras in Chihuahua, Mexico. The system was designed and installed by SunWize with ENSO and supported by the New York State Energy Research and Development Authority, which teamed with Sandia, the

State of Chihuahua and NMSU to develop this project as part of MREP.

The US$38,000 hybrid system paid by USAID was operated from 1999 to 2002 and produced an average of 8.9 kWh/day at 240 volts to the ice-maker. The system Coefficient of Performance (COP) was 0.65 and a total of 97 percent of the energy was supplied by the PV array, while only 3 percent was supplied by the back-up propane generator. Production of ice varied each month due to changes in insolation and ambient temperatures and averaged about 75 kg of ice/day (11.5 kg/sun hour). About every 9 months, the icemaker water lines would need to be cleaned to remove calcium deposits. With a fixed timer setting, the ice-maker operated daily for 3 hours with a dozen 15 minute cycles at night to make ice, except on Sundays (no fishing) [2].

The icemaker performed adequatley for the first three years of operation. The project showed that a properly designed, operated, and maintained PV system can indeed produce a significant and valuable resource, such as ice, even in the middle of the desert. Long-term commitment and follow-up by the Mexican project partners was necessary for continued project success. Unfortunately, there were State political changes and the area faced a severe drought. The lake receded over 2 km. from the ice house by 2003 and the fisherman moved their catch out to the other end of the resevoir. The ice-making system was shut down and has not been operated for the past couple of years.

Figure 3. World's first PV ice-maker developed by SunWize for the fishermen of Chihuahua (1999).

The next significant development for PV refrigeration technology came from SunDanzer in support of NASA. The SunDanzer refrigerator uses thermal storage, and a direct connection is made between the cooling system and the PV panel. This is accomplished by integrating a water-glycol mixture as a phase-change material into a well-insulated refrigerator cabinet and by developing a microprocessor-based control system that allows direct connection of a PV panel to a variable-speed dc compressor. The refrigerator uses a more efficient variable-speed dc compressor.

The unit is designed to run on 90 to 150 watts of PV power (needed for compressor start-up), but only draws about 55 Watts when cycling. During cloudy weather, internal thermal storage keeps products cold for a week, even in a tropical climates. The battery-free unit is designed to work optimally in locations with at least 4 sun-hours per day using a variable speed compressor and peak power tracking. NMSU began testing solar refrigerators in July 2000 at its facilities and later in the field in 2002. Units were field tested on the Navajo Indian Reservation in New Mexico; in Chihuahua and Quintana Roo. Mexico; and the highlands of Guatemala with the Fundación Solar. The unit offers the most economical method for on-site refrigeration for rural people. SunDanzer has now sold over 3,500 solar refrigerators (most on battery systems) and they are literally provided by the container load into Latin America today.

Fig. 4. SunDanzer PV direct drive refrigerator piloted in the indigenous Mayan village of Santa Clara, Quiché, Guatemala by NMSU, NASA, and Fundación Solar in 2002.

3. PV FOR SCHOOLS

Thousands of rural schools in Latin America do not have grid power. Solar power offers a practical way to meet their power needs. Many early school PV systems often failed and gave the technology a poor image. Around 2000, PV school installations in many parts of Latin America began to show great improvements as the industry matured. Large scale rural school electrification programs have been implemented in Mexico, Guatemala, Cuba, Honduras, Peru, and Brazil.

For instance, the Fundación Solar and the Fundación para el Desarrollo Rural de Guatemala began using PV photovoltaics to bring distance education programs to remote areas that were devastated by Hurricane Mitch in 2000. The PV system is used to power televisions, videocassette recorders, and computers to modernize the educational experience of rural schoolchildren.

Mexico has over 500 PV powered schools, with some of the best examples being the 54 PV telesecundaria schools in Chihuahua installed in November, 2002 by EDUSAT/State of Chihuahua for satellite education. MREP provided technical advice to avoid common errors.

The Consejo Hondureño de Ciencia y Tecnología (COHCIT) has installed a half dozen quality PV telecenters/schools in rural Honduras with assistance from NMSU. COHCIT with the World Bank set up a first pilot PV powered telecenter in the community of Montaña Grande near Tegucigalpa in 2003. As a result of this, COHCIT installed 5 more telecenters in 2004 with the Inter-American Development Bank and is planning more.

Fig. 5. COHCIT Sosoal PV satellite telecenter with internet connectivity using quality BOS components with SOLARIS installer Ethel Enamorado in Lempira, Honduras (2004).

4. PROTECTED AREAS

Renewable energy technologies have been widely applied to support protected area throughout Latin America, especially in Guatemala and Ecuador (Galapagos). Mexico with MREP has installed over 70 solar systems in protected areas such as Isla Contoy, El Eden, Montes Azules, and Sian Ka'an Reserves with the Mexican Secretariat of Environment and Natural Resources (SEMARNAT), the Nature Conservancy, World Wildlife Fund, and Conservation International [3].

Use of solar in protected areas benefits the living conditions of researchers, technicians, and rangers, as well as providing energy for environmental training centers. The solar systems also have the advantage of providing power without the noise or pollution associated with conventional fossil-fueled generators, while reducing the risk of fuel spills in these sensitive biosphere reserves. As always, up front design decisions, user operation, and long-term maintenance issues play an important role for overall system reliability.

Solar energy is an environmentally appropriate example to neighboring buffer communities (often without electricity) surrounding biosphere reserves which can likewise benefit by replicating the protected areas example. Solar systems also provide a useful example for visitors and tourists to take back home.

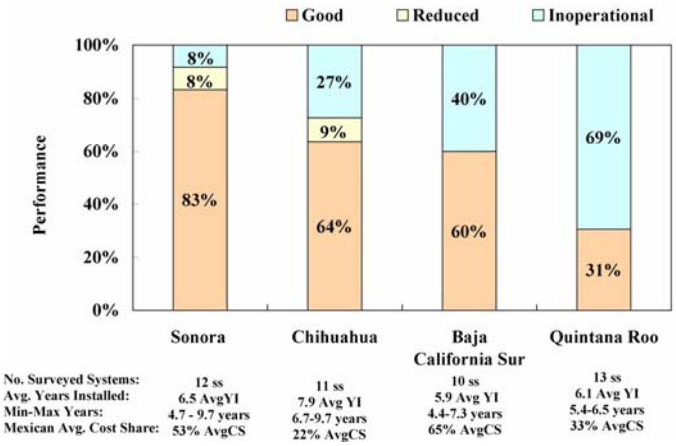
In addition, the remote protected area facilities benefit economically from solar installations through reduced operation and maintenance costs associated with fossil fuel generators. Actual system life-cycle costs for any particular solar or wind energy system varies and is a function of design, usage, application, and maintenance. With proper system operation and maintenance, the expected solar system lifetimes should exceed 25 or more years (with appropriate battery replacements, etc.).

5. PV WATER PUMPING

PV systems have proven to be an excellent option in meeting water pumping where electrical grid service does not exist. Between 1994 and 2005, over 1,700 PV water pumping systems were installed throughout Mexico, initially as part of a MREP- Fideicomiso de Riesgo Compartido (FIRCO) program, and later with GEF/World Bank renewables for agriculture program. PV water pumping was largely unknown in Mexico prior to 1994, and MREP paved the way for widespread adoption in Mexico, which leads Latin America in this application.

FIRCO, NMSU, and Sandia conducted a review in 2004 on 46 of the first installed PV pumping systems. Typical system configurations included a PV array (~500 Wp on average), pump, controller, inverter, and overcurrent protection. Over 3/5 of the surveyed systems were operating appropriately after as much as 10 years. The surveys were conducted in Baja California Sur, Chihuahua, Quintana Roo, and Sonora. A total of 85 percent of users thought that PV systems had excellent to good reliability [4].

Fully 94 percent of users classified water production as excellent or good, with only 2 percent unsatisfied. The survey found that over 4/5 of the rural Mexican users were satisfied with the reliability and performance of their PV water pumping systems. When there were system failures, they were typically pump technology and installer specific.



g. 6: Performance of Mexican PV water pumping systems.

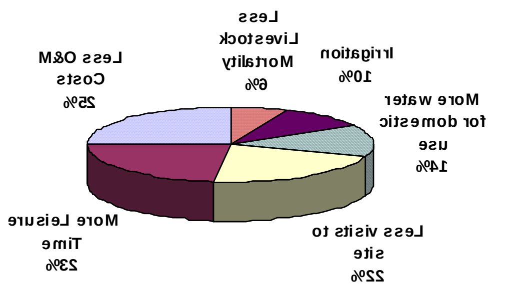


Fig. 7. End-user perceptions in Mexico about the value of a PV water pumping system (27 users persepctive)

When there have been problems, they are mostly due to failure of pump controllers and inverters, or well collapses or drying out due to drought. There were no PV module failures. Investment payback for the PV water pumping systems has averaged about 5-6 years, with some systems reporting paybacks in half that time [4].

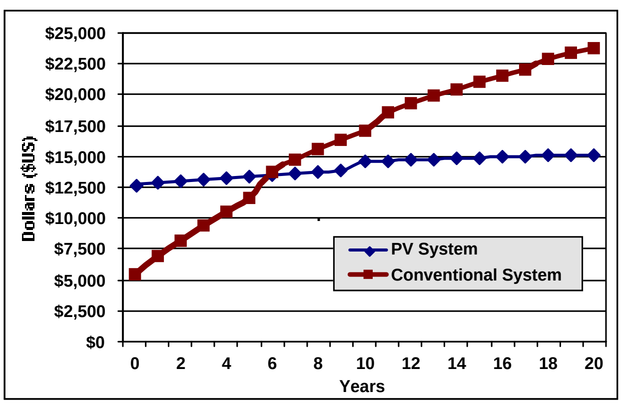


Fig. 8. Life-cycle cost analysis of PV versus diesel pumping at Rancho Agua Blanca, Baja California Sur, Mexico.

4.0 HYBRID SYSTEMS

The road for hybrid system application in Latin America has been difficult. While the various solar technologies are proven, the institutional and organizational issues for these more complicated systems have proved to be the most difficult to overcome. Some of the key hybrid projects implemented in Latin America include the Caampinhas project in Brazil, and the Xcalak and San Juanico systems in Mexico.

In 1992, the State Government of Quintana Roo funded the installation of the world's largest (at that time) wind/solar village hybrid system in Xcalak. The idea was to provide additional hours of power for the community beyond the 3-4 hours per day that the diesel was operated. The combined wind/photovoltaic hybrid system hardware cost was approximately US$450,000 and installed by Condumex. The generation system consisted of six Bergey Windpower nominally rated 10 kW Excel wind turbines and 11.2 kW of Siemens PV modules. Energy was stored in two battery strings using 216 GNB Resource Commander batteries for a combined total of 1738 Ah at 220 volts. The stored energy was provided to the town's electric grid via an Advanced Energy Systems 40 kW sinewave inverter.

Originally the wind and PV system output was adequate to nearly meet the entire village's electric power demand for 24-hour power. However, the village loads rapidly grew after system installation (53% in the first year alone) and there were no electric meters. By 1997 the Xcalak renewables system provided less than 30 percent of total community power due to significantly increased loads and lack of system maintenance [5].

After five years, the system ceased to function altogether, in particular due to the failure of the 40 kW inverter, which faced a difficult job in Xcalak with highly unbalanced system loads and corrosion exacerbated by drawing humid air from below ground concrete raceways.

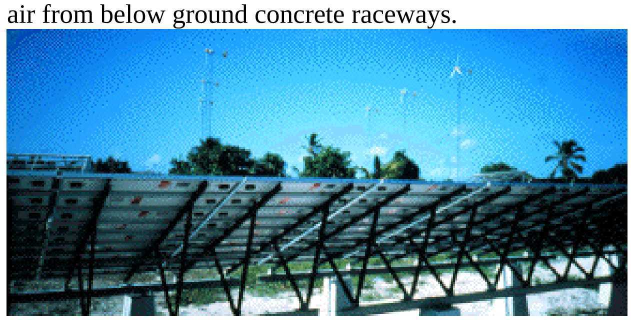


Fig. 9. Xcalak, Mexico wind turbines and PV array (1993).

The early years of the Xcalak hybrid system showed that wind and PV technologies can provide abundant and reliable electric service. However, the lack of institutional planning led to inadequate system maintenance, excessive load growth, and eventual system failure. For hybrid systems to be a viable, an adequate and manageable institutional structure must accompany the technology. To avoid failure, village hybrid systems must include realistic system sizing and proper institutional controls from the onset [5].

6.0 LESSONS LEARNED

When developing solar projects in Latin America, there is a tendency for some organizations to focus on the technology, while other focus largely on institutional issues. The happy medium takes into account both and promotes partnerships, local capacity building, quality technical design, and monitoring and evaluation. Some key considerations for any solar project include the following [6]:

• **Develop Solid Partnerships:** The most sustainable and viable projects are formed when in-country agencies partner with industry. It is important to choose partners carefully.

• **Conduct Strategic Planning**: Strategic planning with collaborating partners helps to create realistic goals that makes PV as a useful tool for established programs. Planning should include sufficient promotional activities to accelerate acceptance, including training.

• **Use grass-roots development approach***:* An integrated and grass-roots development approach across a critical mass of different agency types provides a strong base for dissemination and replication. A local and capable champion greatly facilitates local solar development.

• **Foster reasonable end-user expectations:** Do not oversell PV technologies and capabilities that might disappoint users. End-users want quality systems that work and supplies them the power they need.

• **Create sustainable markets::** Financing is a major barrier to market growth. Renewables must be cost accessible to rural people and often require smart cost-sharing or financing. Reinforce commitment to sustainability and perceived system value from systems that are donated to ones that users find affordable through micro-credit lending.

• **Promote capacity building***:* In-depth training is critical. It is important not only to train project developers, but also users and local industry (supply side). Success depends largely on the technical capacity of local technicians, users, and administrators while considering gender issues. Adopt participatory techniques in community projects.

• **Size Appropriately:** System sizing and design needs to be focused and realistic as to user needs and loads to avoid unnecessary expenditures on larger systems than required. The system needs to meet the loads now and be expandable for the future. Choose energy saving devices to reduce PV system size and save money.

• **Obtain user input:** Clearly identify user needs and develop appropriate technical specifications for a system to meet those needs. Consider technical, gender, and cultural issues as well as economic constraints.

• **Develop a professional design:** Design parameters should be developed by experienced engineers and include realistic system usage, climatic conditions, component selection, O&M considerations, safety, and reliability considerations.

• **Insist on quality:** Installations should be made by experienced technicians that exhibit good workmanship and meet electical code requirements. For larger programs, acceptance testing of installed systems should be conducted to verify that contractual obligations have been met.

• **Conduct preventive and regular maintenance:** O&M is required for long-term successful system operation. There are diverse maintenance levels. Some actions can be undertaken by the end-user, while more complex tasks requiring a skilled technician. Proper tools must be provided. An O&M actions journal is recommended.

• **Anticipate future growth**: Design a system accordingly for relatively seamless expansion.

• **Maintain parts supply inventory:** Required for components that are likely to be replaced (e.g., fuses). Build a strong supplier network. Try to use appropriate local components as much as possible to avoid delays in replacement parts. Facilitate links between the end-users (men and women) and equipment suppliers.

• **Consider safety and security:** Design with safety in mind, meet all applicable codes and standards. Be vigilant as to potential theft, vandalism, etc., and plan accordingly.

• **Demand guarantees and warranties:** Use reputable vendors who offer guarantees and know what these are. Consider long-term preventive maintenance contracts for system support with the equipment vendor.

• **Conduct follow-up and evaluate results**: Monitoring and follow-up are key to understanding the true results for any program. End-user surveys can provide valuable feedback in regard to customer expectations, usage patterns, and overall satisfaction. This information helps with future planning.

• **Think sustainability:** All paths should lead to this and institutions applying solar systems must have a true commitment for long term sustainability. Government agencies face particularly difficult challenges with often changing parties in power. The ultimate goal is to have a well designed and installed solar system that will provide many years of reliable and satisfactory service. The past twenty years have set the stage for future solar development in Latin America, which is growing exponentially.

5. REFERENCES

1. Foster, R. E., L. Estrada, M. Gomez, A. Cota, “Evaluación de la Confiabilidad de los Sistemas FV SOLISTO en Chihuahua,” AR27-02, 12th Intnl. Symposium on Solar Power and Chemical Energy Systems, SolarPACES, 28th Semana de Energía Solar - ANES, Oaxaca, Mexico, October 4-8, 2004.
2. Foster, R., L. Estrada, S. Stoll, M. Ross, and C. Hanley, "Performance and Reliability of a PV Hybrid Icemaking System," 2001 ISES Solar World Congress, Adelaide, Australia, November 25-30, 2001.

3. Romero-Paredes, A., R. E. Foster, C. Hanley, M. Ross, "Renewable Energy for Protected Areas of the Yucatán Península," SOLAR 2003, ASES, Austin, Texas June 26, 2003.
4. Cota, A. D., R. E. Foster, et al, "Ten Year Reliability Assessment of PV Water Pumping Systems in Mexico, SOLAR 2004, ASES, paper #322A, Portland, Oregon, July 9-14, 2004.
5. Foster, R. E., R. C. Orozco, A. Romero, "Lessons Learned from the Xcalak Village Hybrid System: A Seven Year Retrospective," 1999 ISES Solar World Conference Proceedings, Volume I, ISES, Israel Ministry of Science, Jerusalem, Israel, July 4-9, 1999.
6. Richards, B., C. Hanley, R. Foster, et al, "PV in Mexico: A Model for Increasing the Use of Renewable Energy Systems," Advances in Solar Energy: An Annual Review of Research and Development, Volume 13, ISBN: 0-89553-256-5, ASES, Boulder, Colorado, 1999.