Succeeding with Solar School Programs: An Examination of Xcel Energy's *Solar Schools* Program in Colorado

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ABSTRACT

In the *Solar Schools* program, Xcel Energy, a public utility, contracted with a private distributed generation service company for the design and installation of educational demonstration photovoltaic (PV) systems on 29 schools throughout Colorado. Significant program funding was provided by the Renewable Energy Trust, a ratepayer supported fund that provides funding for renewable energy projects at schools and non-profits.

Through the program, PV systems were installed on elementary, middle, and high schools in urban, suburban and rural locations. Installed systems consisted of 2.4 kW of single crystal silicon PV modules, 2.0 kW inverter for grid-tied installations with no back-up storage, electrical generation and rooftop weather monitors, data logger, and a classroom computer connected real-time to the Data Acquisition System (DAS). Ambient conditions as well as system power generation are displayed and archived on the classroom computer.

Program objectives included:

- educate school communities about PV technology;
- provide educational opportunities through real-time data display;
- install as many systems as possible as cost effectively as possible with available funds;
- demonstrate PV technology and its reliability to the school and the community; and
- increase the utility's experience with PV system operation and grid inter-tie issues.

As part of the grant application, school faculty committed to develop solar curriculum using the PV system and data. A significant barrier to curriculum development proved to be teachers' limited technical background with PV systems, electricity fundamentals and computer data analysis.

This paper describes the program implementation process. It reviews the design, installation, and applicable obstacles encountered as well as the approaches taken to overcome them, and an evaluation of how well the program objectives were met.

Overview

Over the past 10-15 years, numerous utilities in a large number of states have participated in photovoltaic (PV) demonstration projects on schools. Public projects such as these have been costly in terms of $/kW or $/kWh. PV is an expensive commodity, and all the more so as a demonstration project for schools already connected to the grid. PV projects, in general, have been and continue to be a learning process for entities interested in generating their own power and connecting to the grid. There can be both a lengthy approval and permitting process required before beginning an installation. And, installation or utility tie-in issues can contribute to lengthening project time-lines. (Piaskoski et al. 2001) Ensuing projects might benefit from lessons learned, but might also be undertaken with some trepidation because the process has been cumbersome.

Progress has been made on many fronts in recent years as issues are dealt with and viable solutions developed. The *Schools Going Solar* project is a broad-based network of schools with PV systems managed by the Interstate Renewable Energy Council. Significant progress can be seen in the *Schools Going Solar* project as more utilities, schools, and states gain experience in these types of projects. Different entities have worked to streamline this process. American Electric Power (AEP) has developed a procurement and installation process that moves rapidly once a school has committed to the program and raised enough money to finance it. AEP also provides information and assistance in all aspects of obtaining a system from initial information dissemination to fundraising to installation (Loeffelman, 2002). Project streamlining progress has been made by others as well, though barriers remain. For the residential PV market, Sacramento Municipal Utility District (SMUD) has committed to streamlining the process to enable homeowners to get PV on their roof through the PV Pioneer Program (Osborne, 2001).

Colorado was a relative latecomer to this type of public PV project endeavor, but in a relatively short period of time, it has put itself on the map in regards to school-based PV demonstration projects. There are a number of reasons for this rapid progress.

This paper shall address Xcel Energy's *Solar Schools* program as a utility-sponsored PV demonstration project. Several of the key features of Xcel's Solar Schools experience will be highlighted as they may prove useful to other entities (e.g., utilities) seeking to increase the number of school-based PV demonstration projects in their service territory. Practices developed that might apply more to a contractor working with a utility will also be examined.

Background

Xcel Energy (formerly Public Service Company of Colorado or PSCo) has had a successful Windsource® Program for making wind-generated electricity available to ratepayers in Colorado since 1996. A renewable energy option for its customers, that was relatively easy for ratepayers to get involved with and not prohibitively expensive, has served Xcel well in seeking to establish its reputation as a 'green' oriented utility.

In another successful 'green' endeavor, Xcel established the Renewable Energy Trust (RET) in 1993 to develop renewable energy resources for non-profit, educational use. The RET is funded by Xcel ratepayers either by rounding their monthly bill up to the nearest dollar (Round Up for Renewables) or making tax-deductible cash contributions. The Denver Foundation, a local non-profit organization that raises and distributes funds to charitable causes, administers the RET. An Xcel customer advisory board reviews and selects projects for RET funding. Xcel manages the marketing, provides technical support for the projects and facilitates the customer advisory board. By 1998, the RET had built up a significant reserve (over $650K) and decided to promote renewable energy through a significant number of public school-based projects that fostered educational opportunities as well.

In 1998, several agencies/organizations, with similar visions and programmatic goals, worked together to increase deployment of renewable energy systems in Colorado while educating students, teachers and community members. Xcel created the RET's *Solar Schools* program to install PV systems at schools throughout its service territory. Xcel worked in conjunction with the Governor's Office of Energy Conservation[1] (OEC) and their own *Colorado Solar Schools Program* for a large percentage of the installations.

The RET's contribution varied with the installation costs and partnering entities, but averaged about $24,000 per system which included the Data Acquisition System (DAS), classroom computer, and a 10 year extended warranty. The OEC participated in 21 school PV installations in conjunction with Xcel and Altair Energy, a local distributed generation service company hired as the general contractor for the installations. The OEC provided financial assistance for half of the total costs incurred, up to a total of $9,000. Additionally, the U.S. Department of Energy's (DOE) Utility Photovoltaic Group (UPVG) provided matching funds through its Building Technology Experience to Accelerate Markets in Utility Photovoltaics (TEAM-UP) program that resulted in a $1.75/Watt buy down on installed grid-connected systems. To date, the RET has supported the installation of 29 school PV systems through its partnership with Altair Energy. It should be noted that OEC also supported a number of school PV installations outside of those with Xcel. Likewise, Altair has installed school PV systems through work with other entities in Colorado.

PV demonstration projects often have involved bringing together several different entities, with similar interests, to collaborate in funding, program design and features, or system design and installation. In coming together, these organizations target completing a certain number of installations that have ranged from one to perhaps a dozen or so projects (Schools Going Solar, 2002). Getting several agencies/entities working together for over 20 PV projects is unusual. Having a utility-sponsored PV demonstration program for schools committing to nearly 30 joint projects with one contractor is rare. Accomplishing both of these is commendable as it demonstrates the level of commitment of the agencies while reducing barriers that have slowed comparable programs.

Timeline of *Solar Schools* Program

The first PV system installed in this program was a 2.4 kW system at Newton Middle School in Littleton, CO. The installation was completed in October, 1998. By June of 1999, only nine months after the first installation, Altair Energy had designed, installed and commissioned 21 PV systems on schools in Colorado through its partnership with Xcel. The *Solar Schools* program has continued to grow, though at a much slower rate due to the need for the RET to replenish itself annually from ratepayer contributions.

Key Program Features for Rapid Deployment

Grid-tied PV installations have often faced significant barriers, though less so in the last several years as utilities, inspectors, and electricians/installers gain experience with issues and acceptable solutions. Costs (components and installation) continue to be the largest barrier, though there are others that can be significant (Hester, 2001). Frequently identified barriers include:

- obtaining site or project approval due to governing offices/departments unfamiliarity with PV installations and issues (Bigger et al. 1999; Hester et al. 2001);

[1] OEC is now known as the Governor's Office of Energy Management and Conservation or OEMC.

- obtaining necessary permits (electrical or building) due to lack of precedence for PV installations in areas of the country (Hester et al. 2001);
- utility inter-tie issues need to be addressed and acceptable solutions agreed upon between installer, PV or building owner, and the utility (Habib, 2001; Hester et al. 2001; Pierson & Pierson, 1998); and
- difficulties in getting electrical installation approved by local, county or state building inspectors (as roughly only 2% of electrical inspectors nationwide have received PV training) (Larsen, Fitzpatrick, & Shirley. 1999).

Xcel, with the input of others, implemented several programmatic features intended to facilitate the installation of as many PV systems as possible as economically as possible. Key program features included:

- creating a streamlined application process to facilitate schools applying;
- contracting with a single entity (Altair Energy) for the design, installation, commissioning and maintenance of all the PV systems, rather than going out to bid on a school-by-school basis; and
- specifying every system to be the same size (with the rare exception of insufficient structural support for the ballasted PV system, in such cases a half-system (1.2 kW) was installed) with the same components to facilitate and simplify structural analysis/installation, electrical analysis/installation, documentation/drawings, and maintenance/repairs

Application process. To promote rapid deployment of PV systems on schools and take advantage of existing funding with the OEC that had both a finite amount of money available for competing projects and a finite timeline for disbursement of the funds, Xcel developed a relatively simple, straightforward application process. Teachers wanting to integrate PV into their classroom represented the target audience for Xcel. To complete the application, interested teachers needed to:

- obtain the approval and signature of the principal and the district superintendent;
- agree to develop PV curriculum that would integrate the PV system and associated software into their existing energy, science, math or computer curricula; and,
- complete a straightforward, several-page application with basic data, i.e., school name and address, grade levels and subjects taught, etc.

By avoiding multiple layers of signatures, approvals and permits from the principal to the building engineer to the superintendent of schools to the school district energy manager to the school board, Xcel simplified a significant potential barrier other utility PV demonstration projects have faced in the past.

Xcel's agreement with Altair included a 10-year extended warranty on the systems and a 10-year preventative maintenance contract. This proved to be a valuable barrier-reducing feature for many schools. Customers want total system warranties for PV systems (Bigger et al. 1999). Being required to take care of an unfamiliar electrical system would have slowed the approval process at many schools and may have even resulted in schools deciding not to participate.

Additionally, there were no funds to be raised by the teacher or the school. The hardware and installation were provided at no cost to the school (an exceptional value!). The systems included not only the PV array and power conditioning equipment, but also a computer, monitor, DAS and software that provided real time and archived data on the monitor in the classroom.

Single contractor. The process of a public PV demonstration project can involve putting the project out to competitive bid for design, installation, commissioning, and maintenance. Then, the utility would identify and select the best bid for the entire project, though it could be broken up into two or more smaller contracts (in the not-too-distant-past, due to lack of familiarity with these types of PV installations, it could be as difficult for the selectors to evaluate the most qualified bidder as it was for the bidders to develop realistic, full cost bids). Upon acceptance of the bid, the selected contractor must: get all necessary permissions/approvals from building personnel; complete structural and wind loading assessment; size, design and locate the system; apply for the necessary permits; obtain utility approval on grid inter-tie requirements; and, order the necessary PV modules or panels and Balance of System (BOS) components. Upon receiving the system components, the contractor must complete the installation, pass code inspection and commission the system for operation. This process may take several to many months. When completed, if another contractor wins the next project put out to bid, the potential benefits of climbing the learning curve lie with the experienced, but unselected, contractor and the new contractor repeats the above steps and incurs the same costs while climbing a parallel learning curve.

Altair Energy was selected as the general contractor for the *Solar Schools* program and was responsible for the entire system design, installation and maintenance process. One of Xcel's overarching program goals was to install as many school PV systems as cost effectively as possible with available funding. Several factors contributed to Xcel's decision to use a single contractor in this initial phase of the *Solar Schools* program, including:

- OEC had grants of $9,000 per school available for a limited time period. Working with Altair enabled Xcel to maximize the number of systems that could access these limited time grants. (Sulko, 2002)
- Altair had a UPVG grant that resulted in a $1.75/Watt buy down for installed systems, other local contractors did not have this buy down available at this time. (Sulko, 2002)
- Altair pursued competitive selection of vendors for materials and services resulting in attractive/competitive prices to Xcel and other clients. (Sulko, 2002)
- The *Solar Schools* program was geared to maximize quality installations and streamline the process for the schools as well as for the utility. (Sulko, 2002)

In Xcel's view, given the circumstances and time constraints for significant funding opportunities, the economics of the utility working with multiple contractors would have ultimately resulted in fewer systems being installed in this initial phase of the program. Other contractors have submitted bids in the 2nd round of school PV system funding.

Altair climbed a significant learning curve initially, but, with each installed system, lessons learned could be applied to future installations. Improvements to the process were made continuously and the timeline for ensuing schools' completion shrank considerably.

One benefit of using a single contractor for multiple installations was the standardization of grid inter-tie requirements. Grid-tied PV installations have often faced barriers, though less so in the last several years as utilities, inspectors, and PV installers gain experience with PV systems, inter-tie issues and solutions. (Hester et al. 2001)

A feature of the *Solar Schools* program, highlighted by the Xcel-Altair partnership, that facilitated a smooth deployment process, was Xcel's Electrical Distribution engineers and electricians working with Altair *before* the initial installations to agree on the necessary inter-tie requirements. The goal was to establish a boilerplate design that could be easily replicated (Sulkko, 2002). During the first few installations, Electrical Distribution engineers made some modifications to the requirements, after which, the grid inter-tie requirements became a standard, routine part of each installation. This eliminated one of the major barriers that individual residential customers often struggle with in trying to tie their own PV system into the local utility grid (Habib, 2001; Pierson & Pierson, 1998).

Upon acceptance of an application by Xcel, the Altair project engineer would conduct a site visit and evaluation at the school. Each school building is different in architecture, construction materials, and local weather considerations. Potential locations in Colorado vary from 4-9,000 feet elevation and many locations experience wind gusts of 60-100 mph at some time during the year. All systems had to be sited individually with consideration of:

- wind loading;
- structural wall and roof loading factors;
- electrical sub-panel feeder location; and
- PV system power control room location (for convenience of tie-in with existing systems and accessibility for both an emergency and routine maintenance situations).

During the site evaluation, the project engineer, in consultation with the school building engineer, would determine an appropriate rooftop location, a suitable electrical sub-panel for system tie-in, and the location of utility emergency shut off switches. A civil engineer utilized weather data and building drawings to perform wind loading and structural analysis to determine the system location and approve system size.

Several licensed electricians, with PV experience, installed the PV and BOS components. In Colorado, as in many states, since most PV installation companies or electricians who specialize in PV installations have rather small staffs (commonly 1-3 person operations), the practice of employing several different electrical contractors enabled concurrent installations to occur with minimal delays.

Installation factors varied. Initial installations involved transporting modules, module inter-connection wire, panel framing and support structures to the roof via crane for assembly into inter-connected panels. At other schools, modules, frames, roofing tiles, and ballast were pulled up onto the roof with a rope or were carried up individually. The third school installation occurred during a snowstorm. The benefits of pre-assembly wiring and framing for panels (panelizing) became apparent as extended periods on the roof during rain, snow or extreme sun proved time-consuming, unhealthy and uncomfortable. Altair began assembling the panels in-house, rather than contracting electricians to do it, thereby reducing costs.

At a number of schools, especially after panelizing the modules became the modus operandi, Altair used a crane to lift PV modules and support hardware to a 2nd or 3rd story roof. Transportation of system components to the school became simpler and easier with pre-assembled pieces as well. Panelization also shortened the amount of time for crane rental.

Identical system components. Having every system consist of identical components helped to facilitate the deployment process and simplify several aspects of Altair's responsibilities. Some of the benefits included:

- system sizing issues are reduced to just structural loading factors;
- one system design can be used for most installed systems;
- multiple components of systems can be ordered with potential bulk purchase discounts while reducing the impact of manufacturer delays due to shipping, backorder or out-of-stock problems;
- replacement part ordering does not delay repairs as needed parts can be pulled from existing inventory; and
- troubleshooting and repair are simplified.

An additional cost, borne by Altair, that contributed to the rapid deployment of PV systems, was to stock components necessary for 5-15 complete systems in inventory at all times so there would be no installation delays once a particular project began.

Benefits of Multi-Project Relationship to the Utility and Contractor

The *Solar Schools* program provided substantial marketing opportunities and benefits to both Xcel and Altair. Media coverage for the first installation was tremendous with local TV stations and newspapers participating. This extensive, free publicity put the *Solar Schools* program in the public eye. Within a short time after the initial installations were completed, Xcel had received enough applications to utilize all of RET's available funding. There are presently about a dozen Colorado schools on the 'waiting list' to receive a PV system through this program.

A benefit of establishing a multi-installation program and contract with a single contractor was that it enabled the development of long-term marketing efforts for both Xcel and Altair. For single installation contracts, there is not much incentive for either side to do extensive marketing. However, with a long-term, multi-project contract in place, each additional completed installation created new publicity and marketing opportunities for both Xcel and Altair. Each installation presented an opportunity to identify the growing *Solar Schools* program with Xcel's commitment to education and to promote Altair's ability to service the grid-tied PV market.

The *Solar Schools* program also provided Xcel management and engineers with significant opportunities to increase their expertise in many aspects of grid-tied photovoltaic systems while demonstrating to their customers the reliability of such systems.

Installed Systems Components

The typical installed system was 2.4 kW (DC), though several 1.2 kW systems were installed due to roof loading factors. Thirty-two Siemens SP75 Pro-charger modules, arranged in four 8-module panels, comprised the 2.4 kW systems as shown in Figure 1.

Figure 1. Rooftop PV System at Ralston Elementary School

Source: Photo courtesy of Altair Energy

Concrete ballasts were employed on flat-roof systems with the ballast sized to meet local wind loading conditions. The concrete ballast system enabled all flat-roof systems to be installed with no roof penetrations for securing the PV system.

The inverter, data logger and AC watt-hour meter were located in the power control room. Omnion 2.2 – 6-DID inverters were used for conversion of PV-generated DC electricity to AC electricity to be fed into a school sub-panel.

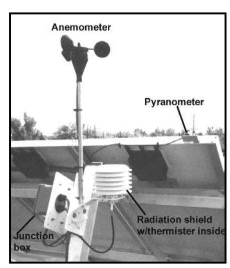
All of the PV systems were grid-tied with no battery backup. Meeting such a small fraction of the school's electric load, there was no critical, identifiable load that could be effectively met during the rare instance of a power outage to justify the cost of developing, installing and maintaining a back-up battery system to complement the PV system.

All systems also included a computer, monitor, DAS and accompanying software for classroom use. As part of the application agreement, the computer was dedicated to the PV system, DAS and *PVDirect* software. It was not to have additional software installed on it. Often, the computer would be located in the classroom of the teacher who submitted the application for this grant. The DAS, computer and software were key components included in the system to enhance the educational possibilities derived from a rooftop PV system. Table 1-1 indicates the DAS instruments used and measurements taken. The rooftop DAS components can be seen in Figure 2 below.

Table 1. Instruments and Measurements

Temperature thermistor	Degrees Celsius
Anemometer	Meters/second
Pyranometer	Watts/meter^2
AC Watt-hour meter	Kilowatts

Figure 2. Rooftop DAS



Source: Photo courtesy of Altair

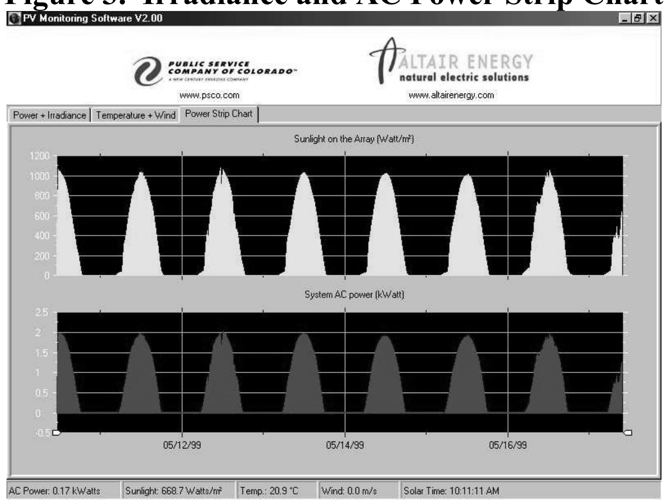
Educational Software Features

Teachers and schools were encouraged to apply to receive the PV system. The teacher(s) submitting the application for the system had to agree to develop PV curriculum and integrate it into the existing energy curriculum in their class. The systems were designed to be an interactive educational tool for use in the science or math classroom. The DAS is connected to a classroom computer and monitor dedicated to the PV system.

The classroom computer utilized *PVDirect®*, a data processing and display software program designed for these school-based PV demonstration projects. The computer monitor displays real-time data for irradiance (Watts/meter^2), AC power produced (kilowatts), wind speed (meters/second) and ambient temperature (degrees Celsius) in cockpit-style gauges.

A seven-day display can be seen in Figure 3 below. This screen provides a strip chart that tracks the plane of array irradiance (Watts/meter^2) and AC power (Watts) produced over variable time frames ranging from the past 15 minutes to the past seven days. The user can simply adjust the time frame for both of these charts simultaneously. The DAS also archived all of the collected data every 15 minutes into monthly ASCII text files.

Figure 3. Irradiance and AC Power Strip Chart



Source: Screen display courtesy of Altair Energy

Altair conducted 2-hour PV system orientation workshops at each school, after the system was commissioned, and typically included a tour of the rooftop system, the power control room, the emergency shut-off switches, and a demonstration of the *PVDirect®* software. The workshops were for schoolteachers, administrators, building engineers and custodial staff. These sessions covered: the basics of how PV works, the costs and benefits of PV, installed system components, safety features, *PVDirect®* software and data files, and educational resources for renewable energy. Teachers were also provided with a notebook with additional renewable energy education resources, both hard copy materials and on-line resources.

Teachers appreciated the introductory workshop and a few were able to infuse that information into their existing or to be developed renewable energy curricula. However, a number of teachers struggled with the PV technology, solar energy concepts, connecting classroom activities to the *PVDirect®* screen displays, and working (either manually or in spreadsheet software) with data sets, like the one depicted in Figure 4 below. Teachers were provided with a wonderful PV system and excellent software, but not enough training for all of them to be able to effectively utilize the systems in the classroom. Schools are excellent locations for PV projects for the purpose of advancing awareness of and education in PV technology. To further this cause, wherever possible, stronger linkages should be made between the school's PV system and the curriculum. (Shirley, Fitzpatrick & Larsen, 1999)

Figure 4. Raw Archived Data in ASCII Format

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"Datetime","REV","AT","POA","WS","PAC"
10-16-1998 12:45:00,0,13.8,152.7,2.8,.2138
10-16-1998 13:00:00,0,11.7,140.2,4.2,.1822
10-16-1998 13:15:00,0,10.3,186.8,3.3,.3096
10-16-1998 13:30:00,0,9.5,79.0,1.6,.0799
10-16-1998 14:30:00,0,8.9,38.8,1.9,0.0
10-16-1998 16:00:00,0,9.3,52.8,1.6,0.0
10-16-1998 16:15:00,0,9.1,32.6,1.8,0.0
10-16-1998 16:30:00,0,8.6,17.5,3.0,0.0
```

Source: Screen display courtesy of Altair Energy

Many teachers have received little or no coursework in PV or electrical systems either in college or professional development while on the job. Finding the right kinds of solar energy materials can be challenging and time-consuming for teachers. (Schleith & Sheinkopf, 2001) The Florida Solar Energy Center (FSEC) has identified this barrier and has developed solutions addressing several aspects of this barrier. "Effective solar energy education requires time, commitment and resources. The simple act of generating activities and making them available is an important first step. It is also imperative to provide professional development opportunities for teachers in order that they expand their content knowledge of solar energy. They should also be provided with proper materials to conduct the hands-on experiments within the activity guide. Technical assistance and follow-up via the Internet or phone is also necessary to ensure the implementation of the products." (Schleith & Sheinkopf 2001, 708)

Professional development opportunities for teachers are necessary to facilitate effective teaching of solar energy topics. Florida teachers participated in daylong workshops and inservice coursework to develop content knowledge necessary to teach solar energy effectively. (Schleith & Sheinkopf, 2001)

The cost of not adequately preparing teachers to teach solar energy may be quite high. The systems have long (20+ years) useful lives. Without utilizing the rooftop system in the classroom on a regular basis, it is possible that systems will be removed from the school's and community's eyes and even forgotten. The teacher(s) that completed the application(s) may change schools or retire. The dedicated computer may be disconnected or moved. All of these speak to underutilized systems. It is not prudent use of ratepayer funding to allow some of the educational opportunities PV systems provide to slip through the cracks. There is much talk these days about sustainable communities, economies, etc. A valuable educational tool with a 20+ year life needs a sustainable education plan for maximum utilization.

Solar Schools Summary

Xcel Energy, with the contracting services of Altair Energy and funding assistance of the OEC and TEAM-UP, has established Colorado among the leaders in school PV demonstration projects.

Xcel effectively met most of its programmatic goals. The reliability of PV technology was effectively demonstrated to the schools and communities as all systems became operational with minimal trouble-shooting and repair required since installation. Xcel engineers gained experience with PV system operation and grid inter-tie issues as the modifications to the original boilerplate demonstrated. Many systems were installed rapidly (21 the first year) and at the contracted price. Program shortcomings can be seen in the educational components. Although the real-time data display provided substantial educational opportunities, they were often not adequately utilized due to the teachers' lack of prior experience with data sets/software and the lack of sufficient teacher training provided through the program. The education of school communities about PV technology fell short, as many teachers did not have adequate backgrounds to enable them to write and utilize PV curriculum. FSEC's model of daylong teacher workshops and inservice coursework may well provide teachers with the content knowledge necessary to develop renewable energy curriculum and more fully utilize the real-time data display.

Some of the designed program features and lessons learned along the way may help other utilities deploy systems more cost effectively and with greater efficiency. To summarize, key features of the *Solar Schools* program for utilities to consider include:

- streamline the approval process and make an application that pertains to essential, pertinent information;
- utilize multiple partnerships or funding possibilities to maximize total funding to develop a program that involves multiple projects and provides for a smaller impact if one or more parties must bow out;
- hire contractor(s) responsible for all projects and for all aspects of system design, permitting (establish necessary inter-tie requirements with the contractor), installation and maintenance (include an extended warranty and maintenance contract) – single contractor or fewer contractors simplifies utility's tasks;
- to the degree possible, make all systems identical in components to simplify design, installation, etc.;
- fully utilize all marketing opportunities; and,
- provide teachers with comprehensive solar energy educational materials, solar devices and activities, and professional development training to promote full utilization of the PV system as an educational tool.

Key *Solar Schools* program features for contractors include:

- utilize multiple subcontractors for concurrent installations and continuous work flow;
- pre-fabricate components/systems as much as possible before transporting to the roof;
- stock multiple systems in inventory so there is no waiting for parts or systems and to facilitate rapid repairs.

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