FINAL TECHNICAL REPORT

Wisconsin Photovoltaic System Case Study

Commercial Application

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Introduction and Executive Summary

The Iowa Department of Natural Resources (DNR) has awarded a contract to Black & Veatch to develop technical case studies for four photovoltaic (PV) applications installed since 1999 in six Midwestern states - Iowa, Illinois, Minnesota, Wisconsin, Missouri and Nebraska. The purpose of these case studies is to independently demonstrate and verify the reliability and viability of photovoltaic systems.

Efforts were made to choose case studies that were diverse in applications and geographic locations. Black & Veatch prepared a questionnaire (Appendix A) and contacted various manufacturers, installers and owners of photovoltaic systems. The key aspect in short-listing applications for the various case studies was availability of elaborate project information and production data. The following case studies were selected from a variety of applications:

- Crandon, Pulaski and Oshkosh-West Public Schools - Wisconsin
- Sac and Fox Indian Settlement Pond Circulator - Iowa
- Ciernia Home - Minnesota
- Kreitman Ranch Water Pumping - Nebraska

This document presents the Wisconsin Public Schools case study. The case study focuses on three public schools that installed 2.3 kW solar photovoltaic systems each. The Wisconsin Public Schools commercial installations have been successfully used as part of an educational campaign for PV systems. The PV installations were funded jointly by the U.S. Department of Energy, Solar Electric Power Association, Wisconsin Energy Bureau and contributions by local utility customers. The installations have net-metering capability and have successfully demonstrated the benefit of solar PV systems in reducing energy costs and emissions.

Black & Veatch collected information on project timeline and history, design, procurement and installation process, operation and maintenance costs, production data and conducted an analysis on energy and emission savings. The results are presented in the next section.

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Crandon, Pulaski and Oshkosh-West Public High Schools - Wisconsin Photovoltaic System Case Study

Project History

The Wisconsin Public Service Corporation (WPSC), a local utility, operates a non-profit education organization, WPS Community Foundation, to provide information and options for renewable energy. The WPS Community Foundation offers a solar energy and education program, SolarWise® for Schools, to high schools served by the utility in northeastern and central Wisconsin. The goal of this program is to install solar-electric systems on all high schools the WPSC serves and educate students and their communities about solar power. Under the SolarWise® for Schools program, customers make tax-deductible donations to the WPS Community Foundation. The donations, along with grants from the State of Wisconsin Division of Energy, are used to purchase and install solar-electric systems on local high schools. The schools receive the solar-electric systems and save money on their electric bills.

SolarWise® for Schools includes several educational initiatives to bring solar power into the classroom. First, teachers at participating schools receive a curriculum package that includes a three-week unit on renewable energy along with a complete set of audiovisual materials and laboratory equipment. Second, student teams from each school are invited to Solar Olympics, a one-day renewable energy fair held at University of Wisconsin-Green Bay. All of these activities help students acquire a deeper understanding of the sun's power.

The Crandon, Pulaski and Oshkosh-West public high schools received funding from the SolarWise® for Schools program in 1999.

Although the utility is the driving force behind this program, local architects, electricians, and roofers were hired to install the equipment. All the installed systems were in compliance with local codes and zoning requirements. The utility did not conduct separate negotiations with any other entities. The development and implementation of this program required assistance from WPSC's Legal, Corporate Accounting, Billing, Marketing and Facility Services departments.

Design, Procurement Process and System Engineering

Schott Applied Power, formerly Ascension Technology, of Massachusetts designed and procured all three PV systems based on standardized building block sub-systems. The WPS Community Foundation selected Schott Applied Power due to its prior relationship in

successful installations of PV systems in other high schools from 1996-1998 under the SolarWise® program.

Since the primary purpose of installations in all three high schools was education and awareness, the size of the system was not governed by the electricity needs of the schools. As a result, WPS Community Foundation decided that the size of each system would be nominal 2.3 kW (7859 BTU/hr) DC.

Schott Applied Power selected the ASE Americas model ASE-300-DG/50 PV modules for each school. They wired eight modules, 4 ft. x 6 ft. each (1.22 x 1.83 meters), in series for all cases. They used Omnion series 2400 inverters with a 3.3 kW (11,262 BTU/hr) rating to convert the DC power to AC power. Schott Applied Power source circuit protectors provided interconnections and lightning protection. The ASE modules carried a standard 10-year warranty and the Ominion inverters had a 2-year warranty.

Schott Applied Power simulated power generation from the modules using a regression model specified by the Solar Electric Power Association-SEPA (formerly Utility PhotoVoltaic Group-UPVG) to estimate performance of the PV modules. The model is specified as:

$$PV = \beta_1 * POA + \beta_2 * POA^2 + \beta_3 * POA * AT + \beta_4 * POA * WS$$

where:

PV: system output power

POA: plane-of-array irradiance

AT: ambient temperature

WS: wind speed

β_i: regression coefficients based on the type of PV modules

The PV modules have a nominal STC [Standard Test Conditions of 1000 Watts/m^2 (317.1 BTU/hr-ft^2), 77 ^{0}F (298 ^{0}K) cell temperature and 1 meter/second (3.28 ft/s) wind speed] DC rating of 285 Watts (972.7 BTU/hr). Each high school building block's design STC DC rating was 2.28 kW (=285W x 8 modules) (7782 BTU/hr). As standard conditions do not normally occur in practice, the DC rating under PTC (PV Test Conditions specified by SEPA) of 1000 Watts/m^2, 25 ^{0}C ambient temperature and 1 meter/second wind speed was 2.06 kW (7031 BTU/hr). Assuming an inverter conversion efficiency of 94 percent, the anticipated PTC AC rating was 1.94 kW (=2.06 kW x 0.94) (6609 BTU/hr) for each of the three systems.

Since the main goal of the PV system installations at all three schools was education, the systems were designed to meet less than 5% of each school's energy requirements.

Installation Process

Schott Applied Power supervised the installation process which was carried out by local contractors. They supplied all system components other than field wiring and conduit. The PV systems were based on standardized, building-block sub-systems. A one-line electrical wiring diagram, reproduced with permission from Schott Applied Power, formerly Ascension Technology, is shown in Figure 1. The diagram illustrates the various sub-systems.

The installation process involved a brief review of building permits. The architects of the school roof truss were consulted to confirm the ability of the roof structure to carry additional loads. Other parties involved in the installation included roofers, local electricians and the phone company. The phone company was involved in the installation of a phone line connected to a modem for the data acquisition system.

Schott Applied Power technicians mounted the arrays of PV modules for all three schools on the roof at a tilt of 25 degrees and an azimuth of 180 degrees (south) using stationary, fixed-tilt RoofJack™ mounting hardware. The mounting hardware consisted of a ballasted system that ensured no roof penetration was needed. The technicians mounted sensors for the data acquisition system on the roof. These sensors consist of a plane-of-array irradiance, wind speed and air temperature monitors that take measurements every 15 minutes. The technicians used three-quarter inch (¾") electrical conduits to run wire from the PV array and sensors on the roof to a mechanical room housing the distribution panels, fuses and inverter. The net metering equipment consisting of a distribution panel, kWh meter, fuses, inverter and the data recorder was also housed in the mechanical room. This equipment connected the PV system to the electric grid to export any surplus electricity generated by the PV system.

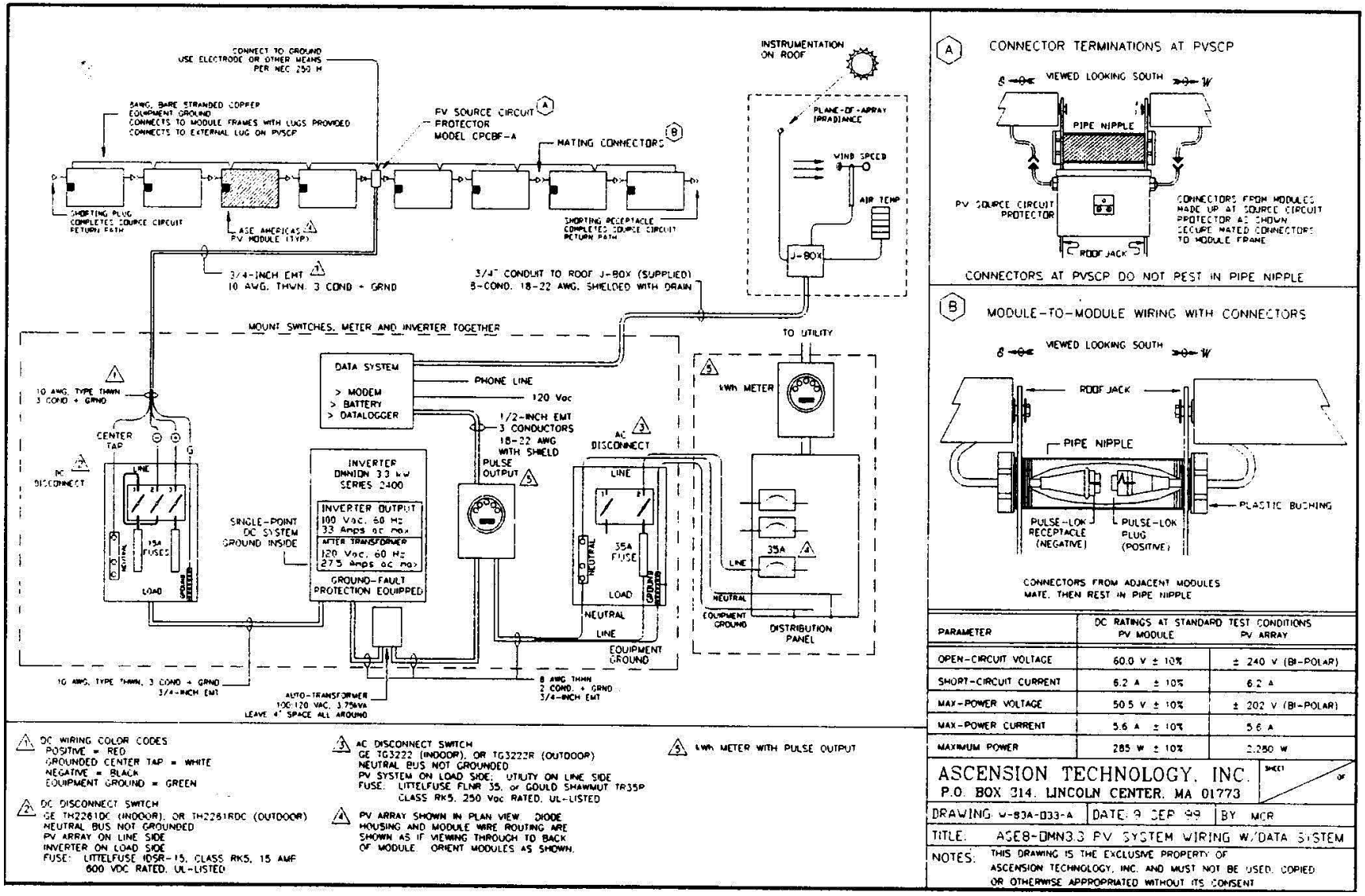
Timeline

In accordance with the design and installation process, the timeline for PV installation at all three schools selected under the SolarWise® for Schools program is shown in Table 1.

Table 1: Wisconsin - Installation Timeline

Event	Date
Schools contacted to initiate discussions for PV installations	April - May 1999
Design, planning and procurement process	June – September 1999
Installations started and completed	First week of October 1999

Figure 1: Wisconsin - System One-Line Diagram



Production Data

Available production data for all three systems is presented in the following tables. Schott Applied Power had simulated the performance of all the systems prior to installation. The actual data and simulated performance for all three schools are listed in Tables 2, 3 and 4. WPSC and Schott Applied Power attributed any difference in actual and simulated conditions to weather conditions like cloud cover and snow.

Legend for Tables 2, 3 and 4:

PV Peak	:	Actual peak PV system production (kW)
PV	:	Actual total PV system energy production (kWh)
PI	:	Performance index (AC measured / AC simulated)
CE	:	Conversion efficiency (%) – Sunlight to AC power
PVs Peak	:	Simulated peak PV system production (kW)
PVs	:	Simulated total PV system energy production (kWh)
POA	:	Plane of array irradiance (W/m^2)
ATC Avg	:	Ambient temperature (^{o}Celsius)

There have been no major operation or maintenance problems with this system except winter snow cover on some days. Data is not available from the Crandon site between July 2000 and April 2002 as records were not maintained. According to WPSC and Schott Applied Power, the PV system was working successfully during that time.

The same system has been installed in numerous schools and no problems have been noticed.

Table 2: Wisconsin - Production Data for Crandon High School PV System

Date	PV Peak (kW)	PV (kWh)	PI	CE (%)	PVs Peak (kW)	PVs (kWh)	POA Peak	POA (W/m^2)	ATC Avg (^oC)
Aug-2002	2.06	320	0.98	9.4	2.04	327	1,156	182.1	19
Jul-2002	1.94	353	0.97	9.1	1.94	364	1,126	206.3	22
Jun-2002	2.21	274	0.94	9.3	2.21	292	1,232	162.3	18
May-2002	2.24	314	0.94	9.6	2.18	334	1,152	178.4	9
Apr-2002	2.14	14.73	0.68	9.6	2.14	21.76	1,122	11.3	4
Jul-2000	1.98	59.36	0.94	9.4	1.95	62.88	1,088	34.9	19
Jun-2000	2.21	285	0.94	9.3	2.25	302	1,251	166.2	16

May-2000	2.10	297	0.95	9.5	2.13	313	1,151	170.4	13
Apr-2000	2.30	263	0.93	9.7	2.27	283	1,180	149.4	4
Mar-2000	2.16	238	0.92	9.8	2.21	257	1,141	133.5	2
Feb-2000	1.86	31.23	0.17	9.7	2.23	185	1,104	92.7	-4
Jan-2000	1.29	10.15	0.06	0.1	1.87	162	921	79.5	-10
Dec-1999	1.53	41.57	0.39	9.8	1.94	106	950	52.8	-7
Nov-1999	1.75	169	0.93	9.8	1.73	181	880	94.0	3
Oct-1999	2.05	183	0.94	9.6	2.05	195	1,073	102.8	6

There have been no operation or maintenance problems with the Pulaski High School system except snow cover during winter months. WPSC did not have available data for the month of September 2000.

Table 3: Wisconsin - Production Data for Pulaski High School PV System

Date	PV Peak (kW)	PV (kWh)	PI	CE (%)	PVs Peak (kW)	PVs (kWh)	POA Peak	POA (W/m^2)	ATC Avg (^oC)
Jul-2002	1.81	106	0.29	8.7	1.91	364	1,100	210.8	24
Jun-2002	1.99	211	0.73	8.9	2.12	288	1,192	164.4	20
May-2002	2.24	303	0.94	9.3	2.31	323	1,253	177.5	11
Apr-2002	2.20	238	0.90	9.4	2.33	263	1,233	143.1	7
Mar-2002	2.11	209	0.91	9.7	2.14	230	1,118	120.2	-3
Feb-2002	1.93	168	0.89	9.6	1.94	188	1,005	98.5	-2
Jan-2002	1.81	109	0.81	9.5	1.92	134	1,003	70.5	-4
Dec-2001	1.54	106	0.87	9.6	1.56	122	789	64.7	-1
Nov-2001	1.64	131	0.92	9.4	1.64	143	886	78.0	6
Oct-2001	1.79	167	0.98	9.4	1.79	170	977	93.5	9
Sep-2001	2.01	233	0.96	9.2	2.07	241	1,162	135.6	15
Aug-2001	1.93	278	0.93	8.9	1.95	298	1,125	172.4	22

Jul-2001	2.02	296	0.96	8.9	2.04	309	1,165	178.6	23
Jun-2001	1.86	174	0.94	8.9	1.88	185	1,084	106.0	19
May-2001	2.09	246	0.95	9.1	2.19	260	1,159	145.6	14
Apr-2001	2.03	219	0.91	9.4	2.04	241	1,111	131.8	8
Mar-2001	2.13	52.45	0.22	9.5	2.25	237	1,173	125.6	-1
Feb-2001	0.37	0.33	0.00	0.0	2.06	168	1,046	86.5	-7
Jan-2001	0.17	0.32	0.00	0.0	1.73	133	903	69.1	-6
Dec-2000	1.05	0.48	0.01	9.3	1.58	94.83	803	49.0	-10
Nov-2000	1.79	15.18	0.12	9.7	1.80	130	968	69.3	1
Oct-2000	1.53	3.53	0.02	9.5	1.76	204	971	113.3	11
Aug-2000	2.10	240	0.78	9.0	2.14	306	1,223	175.6	20
Jul-2000	1.99	311	0.97	9.0	2.02	322	1,162	184.6	20
Jun-2000	2.04	301	0.96	9.1	2.09	314	1,172	177.9	19
May-2000	2.03	298	0.95	9.2	2.04	312	1,111	174.2	15
Apr-2000	2.12	270	0.95	9.4	2.13	284	1,159	155.1	7
Mar-2000	2.12	249	0.97	9.5	2.20	256	1,146	138.4	4
Feb-2000	1.92	165	0.86	9.8	1.91	193	999	101.3	-3
Jan-2000	1.71	104	0.60	9.7	1.78	172	896	88.8	-8
Dec-1999	1.43	46.62	0.36	9.5	1.56	129	812	67.1	-5
Nov-1999	1.80	184	0.94	9.5	1.82	196	980	105.7	5
Oct-1999	1.88	196	0.89	9.4	1.96	220	1,047	120.3	9

The Oshkosh-West system has operated reliably with the exception of snow cover on the PV modules during some days. There was a gap in data collection data for 3 months from February to April 2000 due to a problem with the telephone line connected to the data acquisition system and a wiring error with the temperature sensor that was incorrectly measuring the ambient air temperature.

Table 4: Wisconsin - Production Data for Oshkosh-West High School PV System

Date	PV	PV	PI	CE (%)	PVs	PVs	POA	POA	ATC

	Peak (kW)	(kWh)			Peak (kW)	(kWh)	Peak	(W/m^2)	Avg (^{o}C)
Dec-2000	1.58	34	0.94	9.5	1.59	33.76	819	18.1	1
Nov-2000	1.76	128	0.89	9.5	1.73	126	926	70.1	23
Oct-2000	1.79	211	0.96	9.1	1.76	205	980	117.9	25
Sep-2000	1.98	261	0.98	9.1	1.93	253	1,092	146.8	30
Aug-2000	1.94	303	0.98	8.9	1.89	296	1,097	175.8	34
Jul-2000	1.94	312	0.98	8.9	2.0	305	1,164	181.5	34
Jun-2000	2.03	314	0.98	9.0	2.06	309	1,153	180.6	34
May-2000	2.00	134	0.96	9.1	1.94	133	1,078	77.2	28
Jan-2000	1.67	72	0.35	9.5	1.81	163	925	86.9	5
Dec-1999	1.59	76	0.45	9.2	1.63	131	854	71.0	13
Nov-1999	1.69	210	0.95	9.1	1.71	205	941	114.5	24
Oct-1999	1.66	50	0.96	9.1	1.67	49	923	28.0	24

Financial Incentives

All three projects had the following financial incentives. According to WPSC records for PV systems installed on nine high schools since 1996, approximately 75% of funding came from the TEAM-Up program, 22% from the SolarWise® for Schools program and 3% from Wisconsin Energy Bureau's Renewable Assistance program.

- USDOE TEAM-UP Program

Since 1994, the Solar Electric Power Association (SEPA, formerly the Utility PhotoVoltaic Group) has managed TEAM-UP (Technology Experience to Accelerate Markets in Utility Photovoltaics), a program that helped to develop commercial markets for a wide range of solar photovoltaic technologies. TEAM-UP, a partnership of the utility industry and the U.S. Department of Energy (DOE), provided cost-sharing for selected PV business ventures in the United States. The intent of the TEAM-UP program was to demonstrate and validate PV system hardware installations for various utility/energy service applications and to build confidence among utilities, energy service providers, industry, and customers. The TEAM-UP program is currently defunct.

- Wisconsin Energy Bureau's Renewable Assistance program.

The Wisconsin Energy Bureau, through the state Department of Administration, administers grant funds for renewable energy systems incorporated into construction projects. Funds available are 10 – 20% of the project cost with an upper limit of $75,000. The source of funding is the State Petroleum Violation Escrow Fund. These grants are available to

businesses, municipalities, and non-profit organizations for all renewable energy technologies.

- SolarWise® for Schools program

Under the SolarWise® for Schools program, local utility customers make tax-deductible donations to WPS Community Foundation. The donations are used to fund, purchase and install solar-electric systems on local high schools. As of September 2002, approximately 5,000 WPSC customers donated $90,000 annually to the program.

Project Costs

The combined project costs for all three schools are illustrated in Table 5. Costs separated by schools and sources of funding were not available. The project cost sharing for all three installations was about 75% for WPSC and about 25% for SEPA (formerly UPVG). These costs do not include any costs that WPSC may have incurred in project management. There have been no major operating or maintenance costs associated with the systems except occasional minimal costs (less than $1,000) due to problems with the data acquisition system. Operating activities included snow removal from the PV modules and checking wiring of the telephone line connected to the data acquisition system. WPSC carries out periodic inspections once every 3 months for all the systems.

Table 5: Wisconsin – Combined PV System Costs for Three High Schools (6.9 kW)

PV System Hardware	Data Acquisition Hardware	Site Preparation and Installation	Engineering Services	Total
$49,451	$8,540	$12,000	$8,730	$78,721

Energy and Emission Savings

Based on available information and data from WPSC and Schott Applied Power, Table 6 shows estimates of emission savings only for the months of operation in the first year after installation of PV systems at the three schools. These estimates are for less than 12 months since complete operational data was not available from the data acquisition system at the three sites for varying periods during the first year of operation. These estimates obtained from Schott Applied Power are based on average emission rates of coal-fired power plants *(Reference: PV-Friendly Pricing Report prepared by Schott Applied Power for SEPA in August 2000).*

Table 6: Wisconsin - Emission Offset Estimates during First Year

System Location	Months of Operational Data	Generation (kWh)	Sulfur Dioxide Offset	Nitrogen oxides Offset (lbs)	Particulate Offset (lbs)	Carbon Dioxide Offset (lbs)

	Available		(lbs)			
Crandon	10	1,575	19	22	1	4,163
Pulaski	11	2,199	27	30	1	5,812
Oshkosh	8	1,331	16	18	1	3,518

Based on typical meteorological year solar data for Green Bay, Wisconsin, Schott Applied Power has estimated that each system will generate about 2,900 kWh per year under ideal conditions. The actual generation depends on weather conditions at the local site and will determine the typical amount of energy savings. The annual savings were estimated to be about $80 at each school based on a retail electricity rate of about 2.74 cents/kWh *(Reference: PV-Friendly Pricing Report prepared by Schott Applied Power for SEPA in August 2000)*. This rate seems to be quite low and the savings are expected to be greater in 2002. There were no environmental issues associated with this project.

Lessons Learned

WPSC and Schott Applied Power believe that the following lessons were learned from this project:

1) A reliable data acquisition system is extremely important to verify the operation of the PV system. In this case, due to problems with the data acquisition system and associated phone lines, data ranging from 1 to 4 months was lost at the three schools.
2) WPSC had requested Schott Applied Power to crate the system components including modules, ballast trays, roofjacks and inverters together in one package for each school as opposed to packing all individual components in separate packages. This was very convenient to the installers as frequently, in the past, the steel trays and roofjacks for the ballast-mounting systems had suffered mechanical damage due to mishandling of these components.
3) In addition to energy and emission savings, WPSC believes that the real value of these PV installations has been educational and public outreach opportunities that the program provided to the host schools. The installed systems are used by teachers as “live” classroom laboratories to teach students about renewable energy. In addition, WPSC learned that its customers value PV systems more highly than solar heating systems.
4) Due to a consistent ongoing relationship between WPSC and Schott Applied Power for annual SolarWise® for Schools program, a standard procedure for design and installation was developed.

Appendix A: PV Questionnaire

We are pleased to inform you that Black & Veatch has been selected by Iowa Department of Natural Resources to conduct a case study of solar PV applications installed since 1999 in the Midwest. Please provide the following information as part of the study. We thank you for your cooperation. This report will be distributed widely to engineers, at technical workshops and published over the internet to promote solar PV systems.

Project History

- Project Name, Size and type of PV cell, and Owner or final end user with contact information.
- Reason for choice of photovoltaic system as energy source.
- Negotiations conducted with regulatory authorities and utilities.
- Permitting, zoning and all other applications that were filed.
- Other activities preceding project construction.

Design and Procurement Process

- Selection of type of photovoltaic system among various alternatives.
- System (PV and inverter) sizing procedure, one-line electrical wiring diagram and instrumentation details.
- Who was responsible for sizing the system?
- Procurement process and system delivery time-table including major milestones.

Installation Process

- Installation schedule.
- Capital costs.
- Major hardware components including any tracking system used for installation.
- Ease of finding qualified contractors to do the installation.
- Could the end-user have assembled (direction, azimuth, elevation, wiring, mechanical assembly, etc?) the system by themselves with adequate instructions?
- Lessons learned during construction that can be applied to future projects.

Timeline

- Process time-line from initial vision, system engineering, procurement, installation and start-up.

Operations Costs

- Annual cost of operating and maintaining the system.
- System reliability and major problems faced with operation and maintenance.
- How many times was routine maintenance required annually and is routine maintenance possible by the owner themselves?

Production Data

- Please provide electric production (or water pumping) data or performance summary for any consecutive 12-month period since 1999 to verify system reliability.

Electrical Consumption

- What is the ratio of electricity consumption for the load served by the photovoltaic system against the total electricity produced by the system?
- Applications for which PV-produced electricity was used.

Financial Incentives / Energy and Cost Savings / Economic Analysis

- Financial incentives considered while undertaking project development and other activities preceding project construction.
- Summary of annual energy, monetary and emission savings.
- Tax ramifications/benefits.

Environmental Issues

Environmental issues surrounding operation and maintenance of the photovoltaic system.