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1992 PVUSA Progress Report

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1992 PVUSA Progress Report

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EXECUTIVE SUMMARY

Photovoltaics for Utility Scale Applications (PVUSA) is a national public-private partnership that is assessing and demonstrating the viability of utility-scale photovoltaic (PV) electric generating systems. This report updates the progress of the PVUSA project, reviews the status and performance of the various PV installations during 1992, and summarizes key accomplishments and conclusions from work to date.

BACKGROUND

Falling PV module costs and rising environmental pressures could make PV a significant source of large-scale power within the next decade. However, utility acceptance of this technology requires knowledge of PV operational characteristics in a utility system and confidence in predicting PV performance, reliability, and economics.

PVUSA offers utilities hands-on experience needed to evaluate and utilize maturing PV technology. The project also provides manufacturers a test bed for their products, encourages technology improvement and cost reductions in PV modules and other system components, and establishes communication channels between utilities and the PV industry.

PVUSA participants include the U.S. Department of Energy, the California Energy Commission, the Electric Power Research Institute (EPRI), Pacific Gas & Electric (PG&E), and ten utilities and other energy-related agencies. PG&E leads the PVUSA Project Team, which manages daily activities and facilitates technology transfer.

PROJECT SCOPE

PVUSA consists of two types of demonstrations: Emerging Module Technologies (EMTs), which are unproven but promising state-of-the-art PV technologies in 20-kW (nominal) arrays; and Utility Scale (US) systems, which represent more mature PV technologies in 200- to 500-kW (nominal) turnkey systems.

PVUSA's primary test site in Davis, California, is the location of five EMT arrays and three US systems. The project, begun in 1987, consists of three EMT procurements (EMT-1, EMT-2, and EMT-3) and two US system procurements (US-1 and US-2). The US-2 procurement is a 500-kW grid support application demonstration which was installed in 1992 and early 1993 near PG&E's Kerman, California, substation. Other test sites are located in service areas of participating U.S.

host utilities, including the electric utility department of the City of Austin, Texas, Long Island Lighting Company (LILCO), Maui Electric, and Virginia Electric Power Company (VEPCO).

Tables ES-1, ES-2, and ES-3 list PVUSA EMT, US, and host utility system suppliers, completion dates, PV technologies employed, and system sizes. All completion dates in this report are as of April 1993.

ACCOMPLISHMENTS

Specific accomplishments achieved during 1992 are listed below.

Procurement and Installation

EMTs. AstroPower and Golden Photon continued with development and qualification testing for their EMT-2 modules. Contracts were awarded for three EMT-3 arrays, scheduled for installation in 1994. The manufacturers of these arrays are Amonix, Solar Cells Inc., and SunPower. (SunPower's contract was subsequently withdrawn by SunPower due to the company's lack of funding.)

US Systems. The Advanced Photovoltaic Systems (APS) US-1 system was formally accepted by PVUSA, becoming the first completed US-1 system. Installation of the other two US-1 systems continued. Siemens Solar Industries (SSI) stopped field testing to modify the two Dickerson inverters that had experienced ongoing startup problems. The Integrated Power Corporation (IPC) system panels were retrofitted in the field with standard junction boxes to replace wiring harnesses and disks that had failed PVUSA's field acceptance tests. In April, a contract was awarded for a US-2 system, a 500-kW grid-support PV installation near PG&E's Kerman, California, substation. The site development, infrastructure, grid interconnection, and SCADA system were designed and constructed by the PVUSA Project Team. By year's end, the manufacturer, SSI, had nearly completed system installation.

Performance

The APS US-1 system was rated at 479 kW ac at PVUSA test conditions, 79 kW over the contract rating. PVUSA systems in Davis, Maui, and Austin together generated 441,943 kWh in 1992—enough to satisfy the electricity requirements of about 70 homes. Since the project's initial generation of electricity in 1989, PVUSA systems supplied over 900,000 kWh through 1992, with the millionth-kWh milestone approaching rapidly as additional US systems come on-line in 1993. Annual capacity factors for the various arrays ranged from about 9 to 19 percent.

**Table ES-1
PVUSA Davis EMT Systems**

Completion Date	Supplier	Technology	dc System Efficiency (%)¹	dc Power (kW)¹
	EMT-1			
1/89	Siemens Solar (ARCO)	Microgridded single-crystal silicon	11.1	18.7
6/89	Sovonics-Davis	Tandem junction amorphous silicon	3.5	17.3
12/89	Utility Power Group	Tandem junction amorphous silicon	3.3	15.7
10/90	Solarex	Bifacial polycrystalline silicon	8.6	15.7
3/91	ENTECH	22x linear concentrator, crystalline silicon	11.3	16.5
	EMT-2			
3rd Q/93 ²	AstroPower	Thin-film polycrystalline silicon on ceramic	7.4 ⁴	19.3 ⁴
1st Q/94 ²	Golden Photon ³	CdTe	5.3 ⁴	18.7 ⁴
	EMT-3			
2nd Q/94 ²	Solar Cells	Polycrystalline thin film CdTe	7.3 ⁴	19.7 ⁴
3rd Q/94 ²	Amonix	260x Fresnel point-focus concentrator, FZ-Si back-contact cells	17.8 ⁴	20.0 ⁴

¹ Based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1000 W/m² plane of array irradiance, 20°C ambient temperature, and 1 m/s wind speed. (For concentrators, a direct normal irradiance of 850 W/m² is used.)

² PVUSA project estimate as of April 1993.

³ Formerly Photon Energy.

⁴ Based on supplier's estimate (system yet to be accepted by PVUSA).

Table ES-2
PVUSA Davis and Kerman US Systems

Completion Date	Supplier	Technology	ac System Efficiency (%) ¹	ac Power (kW) ¹
	US-1			
3rd Q/93 ²	Siemens Solar (200 kW)	Single-crystal silicon, one-axis passive tracking, Bluepoint PCU	10 ³	174 ³
2nd Q/93 ²	Integrated Power Corp. (200 kW)	Ribbon silicon (Mobil Solar EFG), one-axis active tracking, Omnion PCU	7.4 ³	180 ³
4th Q/92	Advanced Photovoltaic Systems	Amorphous silicon, fixed tilt, APS PCU	4.2	479
	US-2 Kerman			
2nd Q/93 ²	Siemens Solar	Single-crystal silicon, one-axis passive tracker, Omnion PCU	10 ³	501.9 ³

¹ Based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1000 W/m² plane of array irradiance, 20°C ambient temperature, and 1 m/s wind speed.

² PVUSA project estimate as of April 1993.

³ Based on supplier's estimate (system yet to be accepted by PVUSA).

**Table ES-3
PVUSA Host Systems**

Completion Date	Host Utility Sponsor	Supplier	Technology	dc System Efficiency (%)¹	dc Power (kW)¹
10/89	Maui Electric	Sovonics EMT-1	Tandem junction amorphous silicon	3.7	18.5
mid-93 ²	VEPCO	AstroPower EMT-2	Thin-film polycrystalline silicon on ceramic	7.4 ³	20 ³
7/92	City of Austin	IPC US-1	Ribbon silicon (Mobil Solar EFG), one-axis active tracking, Omnion PCU	8.4	17.9
mid-93 ²	NYSERDA	IPC US-1	Ribbon silicon (Mobil Solar EFG), one-axis active tracking, Omnion PCU	8.4 ³	20 ³

¹ Based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1000 W/m² plane of array irradiance, 20°C ambient temperature, and 1 m/s wind speed.

² PVUSA project estimate as of April 1993.

³ Based on supplier's estimate (system yet to be accepted by PVUSA).

Reliability

The APS US-1 system experienced minimal failure-related downtime during its first four months of operation in late 1992. The system availability remained high, capturing over 96 percent of the total insolation. Some of the EMT arrays did experience failure-related downtime, not an unusual result for first-time field tests of emerging and unproven technologies. Some of the downtime may also be attributable to PVUSA research activities that do not always allow for immediate repair of failures.

Safety

An Injury and Illness Prevention Program and a Safety and Health Action Plan were in final review by year's end.

Technology Transfer

PVUSA gave presentations at the following conferences: SOLTECH 92, ASME International Solar Energy Conference, NREL PV Advanced Research and Development 11th Review Meeting, Sandia/DOE Crystalline PV Technology Project Review meeting, and NREL PV Performance and Reliability workshop. An electrical design criteria document and a civil and structural design criteria document were initiated for the Kerman installation; these documents will be finished in 1993. The PVUSA Davis site hosted 147 tours for 598 visitors representing more than 20 countries.

Planning

PVUSA began a formal evaluation process focusing on the long-term objectives of the project. The evaluation is to culminate in a plan that will address engineering and design, construction, data acquisition and analysis, balance-of-system (BOS) costs, and operations and maintenance (O&M), for the Davis, Kerman, and host utility systems, as well as long-term operation of the Davis and Kerman sites. PVUSA also began looking at its technology transfer process. A strategy continues to evolve for providing PV performance, reliability, cost, and safety information to PG&E, other utilities, and the PV industry, and for encouraging utility and public acceptance of PV.

CONCLUSIONS

The technical and financial challenges involved in bringing innovative module and BOS technologies into the field have caused significant, unanticipated delays. Schedule slippages have been due primarily to manufacturing delays and module qualification difficulties.

The SSI Kerman US-2 system has been the most timely of all PVUSA installations. A period of just over 10 months is expected from contract award to release for operation. The Kerman system

uses more proven components than the EMT and US-1 systems, and thus is a more realistic indicator of the construction schedule to be expected for a utility-scale PV installation.

Operational experience with Kerman and the other US systems will be one of the most valuable aspects of the project, yielding key data on performance, equipment longevity, and O&M requirements of large-scale-PV systems.

It is likely that commercial PV technologies will differ somewhat from their predecessors at PVUSA as improvements in efficiency, reliability, and module cost are realized. However, lessons learned from experience with EMTs have been used to build a database for evaluating system component performance and have already been useful in developing the next generation of PV system technology.

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Section 1 INTRODUCTION

The following section provides information on PVUSA's goals and scope, technologies, project sites, schedule, participants, and funding.

BACKGROUND

With the cost of PV modules continuing to fall and environmental pressures mounting, PV could be a significant source of power within the next decade. However, acceptance of this technology by the utility industry requires knowledge of PV operational characteristics in a utility system and confidence in predicting the performance, reliability, and lifetime economics of PV.

PVUSA is a national public-private partnership that is assessing and demonstrating the viability of utility-scale PV electric generating systems. PVUSA offers utilities hands-on experience needed to evaluate and utilize maturing PV technology, provides manufacturers a test bed for their products, and encourages technology improvement and cost reductions in PV modules and BOS components. The project also establishes the communication channels between utilities, government laboratories, and the PV industry that will be necessary for successful development and commercialization of utility PV systems.

The project consists of EMTs and US systems. EMTs are promising, state-of-the-art PV module technologies that have not yet been field tested. The 20-kW size of the EMT arrays was selected to demonstrate ease of manufacture and allow a statistically credible evaluation, while minimizing the risks associated with a new technology.

PVUSA is fielding EMT arrays primarily to encourage promising PV module technologies to move out of the laboratory and into pilot production. During this evolution, EMT manufacturers can determine if the manufacturing process merits further development or scale-up. Lessons learned by manufacturers will be important input for PV technology commercialization decisions. EMTs also allow PVUSA to establish baseline information in relation to the various components making up the array (e.g., junction boxes, inter-array wiring). This information is of interest regardless of the future commercialization of the full array. In addition, EMTs provide PVUSA with an opportunity to develop and establish procedures for performing and tracking PV system O&M, which will be used as a basis for developing corresponding procedures for the US systems.

US systems also offer valuable information for utilities. US systems are vendor-optimized turnkey PV systems representing mature module technologies that have the potential to produce low-cost energy and also meet the O&M, power quality, reliability, and lifetime requirements necessary for utility applications. The US systems selected for demonstration are nominally 200 kW and larger; they are expected to capture much of the economies of scale of larger systems and provide realistic evidence of satisfactory system protection requirements, installation requirements and costs, system performance, O&M costs, and grid interaction. These systems incorporate innovative BOS designs that are expected to lead to cost-effective approaches for utility applications. They also provide both the project participants and the PV industry with exposure to commercial procurement and construction practices.

PROJECT SITES

Most of the EMT arrays and US systems are located at PVUSA's main test site in Davis, California. Figure 1-1 presents a photograph of the Davis site. In addition, a 500-kW US system has been installed near the PG&E Kerman substation 15 miles west of Fresno, California. The focus of the Kerman installation is to evaluate the costs and benefits of distributed PV generation strategically located in PG&E's electrical transmission and distribution (T&D) system, as an alternative to traditional T&D capital upgrades. Figure 1-2 presents a photograph of the Kerman site.

Several utilities are hosting PVUSA systems in their service territories. Maui Electric/State of Hawaii installed a 18.5-kW EMT system in 1989; the City of Austin, Texas, completed installation of a 17.9-kW US system this year; and by year's end, VEPCO and New York State Energy and Research Development Authority (NYSERDA) were in the process of completing host installations. (NYSERDA's 20-kW system was completed but had not yet been paralleled with the LILCO grid.) Central and Southwest Utilities Company, Sacramento Municipal Utility District, and Public Service Company of Colorado are new project participants as of April 1993. All intend to install PVUSA host systems in their service territories.

Figure 1-1
PVUSA Davis, May 1992

Figure 1-2
PVUSA Kerman, January 1993

SCHEDULE

EMTs

At Davis, EMT-1 consists of five 20-kW (nominal) arrays, EMT-2 consists of two 20-kW arrays, and EMT-3 consists of two 20-kW arrays; a third EMT-3 array was withdrawn when the manufacturer failed to realize adequate funding. All EMT arrays were, or will be, installed with PVUSA-supplied BOS components. EMT-1 and EMT-2 arrays use Delta Electronic Control Corporation (DECC) Helionetics inverters of 25 kW nominal size. Proposals will be solicited for new EMT-3 PCUs.

The EMT-1 arrays were completed in early 1991; installation of the EMT-2 arrays is scheduled for 1993. By the end of 1992, contracts had been awarded for the EMT-3 arrays, and preliminary module testing was under way.

US Systems

US-1 at Davis consists of three systems: nominal sizes are one 400-kW and two 200-kW. US-2 consists of a 500-kW system at Kerman.

By year's end, the 400-kW US-1 system had been completed; installation of the two 200-kW US-1 systems continued with completion scheduled for 1993; and the Kerman US-2 system was nearly completed. Negotiations were terminated with a second US-2 system vendor due to PVUSA funding limitations.

Figure 1-3 provides an overall schedule. Tables 1-1, 1-2, and 1-3 list PVUSA EMT, US, and host utility system suppliers; completion dates (as of April 1993); PV technologies employed; and system sizes.

▽ Issue RFP ■ Award Contract ▲ Complete Installation

Completion dates do not apply to host systems.

Figure 1-3
PVUSA Overall Schedule

**Table 1-1
PVUSA Davis EMT Systems**

Completion Date	Supplier	Technology	dc System Efficiency (%)¹	dc Power (kW)¹
	EMT-1			
1/89	Siemens Solar (ARCO)	Microgridded single-crystal silicon	11.1	18.7
6/89	Sovonics-Davis	Tandem junction amorphous silicon	3.5	17.3
12/89	Utility Power Group	Tandem junction amorphous silicon	3.3	15.7
10/90	Solarex	Bifacial polycrystalline silicon	8.6	15.7
3/91	ENTECH	22x linear concentrator, crystalline silicon	11.3	16.5
	EMT-2			
3rd Q/93 ²	AstroPower	Thin-film polycrystalline silicon on ceramic	7.4 ⁴	19.3 ⁴
1st Q/94 ²	Golden Photon ³	CdTe	5.3 ⁴	18.7 ⁴
	EMT-3			
2nd Q/94 ²	Solar Cells	Polycrystalline thin film CdTe	7.3 ⁴	19.7 ⁴
3rd Q/94 ²	Amonix	260x Fresnel point-focus concentrator, FZ-Si back-contact cells	17.8 ⁴	20.0 ⁴

¹ Based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1000 W/m² plane of array irradiance, 20°C ambient temperature, and 1 m/s wind speed. (For concentrators, a direct normal irradiance of 850 W/m² is used.)

² PVUSA project estimate as of April 1993.

³ Formerly Photon Energy.

⁴ Based on supplier's estimate (system yet to be accepted by PVUSA).

Table 1-2
PVUSA Davis and Kerman US Systems

Completion Date	Supplier	Technology	ac System Efficiency (%)¹	ac Power (kW)¹
US-1				
3rd Q/93 ²	Siemens Solar (200 kW)	Single-crystal silicon, one-axis passive tracking, Bluepoint PCU	10 ³	174 ³
2nd Q/93 ²	Integrated Power Corp. (200 kW)	Ribbon silicon (Mobil Solar EFG), one-axis active tracking, Omnion PCU	7.4 ³	180 ³
4th Q/92	Advanced Photovoltaic Systems	Amorphous silicon, fixed tilt, APS PCU	4.2	479
US-2 Kerman				
2nd Q/93 ²	Siemens Solar	Single-crystal silicon, one-axis passive tracker, Omnion PCU	10 ³	501.9 ³

- ¹ Based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1000 W/m² plane of array irradiance, 20°C ambient temperature, and 1 m/s wind speed.
- ² PVUSA project estimate as of April 1993.
- ³ Based on supplier's estimate (system yet to be accepted by PVUSA).

**Table 1-3
PVUSA Host Systems**

Completion Date	Host Utility Sponsor	Supplier	Technology	dc System Efficiency (%)¹	dc Power (kW)¹
10/89	Maui Electric	Sovonics EMT-1	Tandem junction amorphous silicon	3.7	18.5
mid-93 ²	VEPCO	AstroPower EMT-2	Thin-film polycrystalline silicon on ceramic	7.4 ³	20 ³
7/92	City of Austin	IPC US-1	Ribbon silicon (Mobil Solar EFG), one-axis active tracking, Omnion PCU	8.4	17.9
mid-93 ²	NYSERDA	IPC US-1	Ribbon silicon (Mobil Solar EFG), one-axis active tracking, Omnion PCU	8.4 ³	20 ³

¹ Based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1000 W/m² plane of array irradiance, 20°C ambient temperature, and 1 m/s wind speed.

² PVUSA project estimate as of April 1993.

³ Based on supplier's estimate (system yet to be accepted by PVUSA).

PARTICIPANTS AND FUNDING

PVUSA is a national cooperative research and development project. Participants include:

Government Agencies/Research Institutes

- U.S. Department of Energy
 - Jet Propulsion Laboratory
 - National Renewable Energy Laboratory
 - Sandia National Laboratories
- Electric Power Research Institute
- California Energy Commission
- U.S. Department of Defense Tri-Service PV Review Panel

Utilities/Other Agencies

- Pacific Gas and Electric Company
- Central and South West Services, Inc.
- City of Austin, Texas
- New York State Energy Research and Development Authority
- Niagara Mohawk
- Public Service Company of Colorado
- Salt River Project
- San Diego Gas and Electric
- Sacramento Municipal Utility District
- State of Hawaii/Maui Electric
- Virginia Power/Commonwealth of Virginia

Additional participation by utilities and research organizations is encouraged. For additional information, please contact the PVUSA project office, (510) 866-5569.

The project's management structure consists of three groups: the Steering Committee (SC), which coordinates overall project direction and approves scope, schedule, and budget; the Technical Review Committee (TRC), which assesses and reviews technical aspects of the project; and the Project Team, managed by PG&E, which conducts daily activities and facilitates technology transfer.

Total project expenditures are approximately \$24 million (financial) through the end of 1992. Project costs for 1993 are currently estimated at \$5.2 million. Spending for 1994 and beyond is presently under review. Committed funding from PVUSA sponsors is shown in Table 1-4.

Table 1-4
Funds Expended Through 1992 by PVUSA Sponsors

Organization	Amount (millions of dollars)	Percent
PG&E	8.5	36
DOE	11.2	47
EPRI/CEC	3.7	16
Other Cosponsors	0.27	1
Total	23.67	100

REPORT FORMAT

This report describes PVUSA activities during 1992 and is divided into the following sections:

- This section (Section 1) discusses PVUSA's goals and scope, technologies, project sites, schedule, participants, and funding.
- Section 2 describes 1992 procurement, construction, and installation activities, and reviews the status of all systems.
- Section 3 describes the objectives and results of factory and field qualification tests, and summarizes the results of field wet resistance and performance tests.
- Section 4 briefly describes the PVUSA data acquisition systems for the Davis and Kerman sites; analyzes key performance areas for the six EMT-1 arrays in operation; summarizes overall performance for the year; analyzes energy production, efficiency, capacity factor, and system availability; and describes O&M activities.
- Section 5 describes other 1992 activities and site safety planning.
- Section 6 presents key findings to date in the areas of procurement and construction, engineering, performance, O&M, and technology transfer.
- Section 7 presents conclusions and recommendations for future work.
- Appendix A contains weather data.
- Appendix B contains detailed monthly weather and performance summaries.
- Appendix C contains detailed O&M summaries.
- Appendix D contains information on PVUSA systems at host sites.
- Appendix E contains a description of the Kerman site and an electrical diagram of the Kerman US-2 system.
- Appendix F contains a schematic of the PVUSA qualification test sequence.

- Appendix G lists technology transfer activities.
- Appendix H contains definitions of technical terms and abbreviations that appear in this report.

Section 2

Procurement, Construction, and Installation

This section describes 1992 procurements and selections of EMT-3 and US-2 technologies, summarizes 1992 construction and installation activities, and reviews the status of all systems.

PROCUREMENT

PVUSA procurement involves significant ongoing interaction between project staff and management, vendors, and the PVUSA SC and TRC. Each PVUSA Request For Proposals (RFP) is based on lessons learned from earlier procurement cycles.

Procurement for EMT-1, EMT-2, and US-1 installations was completed prior to 1992, with the exception of PVUSA host systems. Descriptions of the host systems and sites appear in Appendix D.

As a result of the experience gained with the EMT-1 and EMT-2 procurements, the EMT-3 process includes a 1-kW test of vendors' PV technology supervised by the National Renewable Energy Laboratory (NREL) or Sandia National Laboratories (Sandia) after the required qualification tests. After several months of evaluation of the 1-kW array, the data are presented to the PVUSA TRC which makes a recommendation to the Steering Committee. A decision is then made regarding procurement of the 20-kW system. The EMT-3 procurement process is illustrated in Figure 2-1.

The US-2 RFP includes an independent design safety review of the PCU, incorporation of the most current NREL and Sandia qualification documents, and upgrades of the contractors' safety program and fire prevention and protection program requirements.

Procurement began in 1991 for three Davis EMT-3 arrays and the Kerman US-2 system. The EMT-3 and US-2 suppliers, their PV technologies, and system characteristics appear in Tables 1-1 and 1-2.

Figure 2-1
PVUSA EMT-3 Procurement Process

Contracts for three EMT-3 arrays were awarded in early 1992 to Solar Cells, SunPower, and Amonix. By year's end, Solar Cells had made significant progress toward module qualification. SunPower's work was suspended when the company withdrew from its contract due to lack of funding. The contract was subsequently terminated by mutual agreement. Amonix experienced delays in module qualification for budgetary reasons. The modules were scheduled for a 1-kW test at NREL in late 1992, in conjunction with an EPRI demonstration. The EPRI project was delayed due to budget constraints, thus delaying the Amonix testing.

An RFP for a US-2 system at Kerman was issued in January, and a contract was awarded to SSI in April. The focus of the Kerman installation is to evaluate the costs and benefits of distributed generation strategically located in PG&E's T&D system as an alternative to T&D capital upgrades.

Unlike the Davis systems, which focus on technology innovation, the Kerman demonstration focuses on distributed system value; as a result, the system was chosen based on its use of proven technologies and was purchased at a system price of about \$9.00/W. The Kerman system is a 500-kW single-axis passive tracking system from SSI. It uses two Omnion inverters, 12,240 SSI single-crystal silicon modules installed among nine rows, and a network of Robbins trackers. A description and a schematic diagram of the Kerman system appear in Appendix E.

CONSTRUCTION AND INSTALLATION

Progress in construction and installation was attained in the following areas:

EMT-2

No construction activity occurred for EMT-2 arrays due to continued manufacturer delays in technology development and testing.

- Due to difficulties in acquiring acceptable module yields, SSI withdrew from its contract for copper indium diselenide (CIS) module technology in August.
- AstroPower's modules are currently scheduled for delivery in August 1993. The manufacturer experienced delays in factory qualification testing.
- Construction continued on a 20-kW PVUSA AstroPower array at Virginia Power. Completion is scheduled for mid-1993.
- Photon Energy was acquired by Golden Technology Corporation in the third quarter of 1992. Photon Energy was renamed Golden Photon, Inc. Golden Photon module delivery is currently scheduled for early 1994. By the end of 1992, Golden Photon had not yet produced a prototype model of sufficient output to begin qualification testing.

US-1

- SSI stopped field testing in August to undertake modifications to the Blueprint (Dickerson) inverters. One inverter was revamped and reinstalled for field monitoring; factory safety and repackaging modifications continued on the second inverter, which was returned to the field in January 1993. The inverters had experienced ongoing problems with start-up, dc ground faults, and dc current transducer failures. In addition, one of the system's 32 Robbins passive tracker actuators, which use R-22 as a working fluid, was replaced with a unit which uses R-134a. The temporary replacement allowed SSI to obtain operational data on the R-134a, which is used in the SSI US-2 system at Kerman. (R-134a is considered to have less environmental impact than R-22.) Preliminary results showed the tracker with the R-134a is more responsive than the others. System completion remained uncertain while SSI continued troubleshooting and monitoring work on the PCU. Current estimates call for completion in the third quarter of 1993.
- Full start-up for the IPC system was delayed because of problems with the Mobil Solar Energy Corporation (MSEC) module interconnection disks, which are used in lieu of conventional junction boxes. The system had been operating since November 1991 with 10 of 11 source circuits. Nine percent of the system's wiring harnesses had failed PVUSA's

field acceptance tests and, as a temporary solution, enough repaired harnesses were available to complete 10 circuits. Several MSEC disk and harness failures—including electrical leakage and melting—were discovered in 1992 at NREL and the PVUSA Davis site. The system was taken off line, and MSEC began retrofitting the modules in the field with conventional junction boxes. A field retrofit was undertaken to reduce the risk of handling damage and avoid the cost of removal, shipping, and replacement. Preliminary tests conducted prior to retrofit work indicate that this system will exceed its contractually required power rating. Completion, including final system acceptance and rating, is currently scheduled for June 1993.

- Construction of the APS system was completed in August. The system was formally accepted by PVUSA in December, having passed all required acceptance and performance tests. The APS array contains 9600 modules, arranged in five rows. Each row contains 24 sections, each section contains eight panels, and each panel contains 10 modules. Construction of the array was accomplished as follows. Two concrete caissons were built to support the front of each section, and two 3-inch diameter steel tubes supported by screw anchors were installed to support the back. A steel truss was put in place horizontally and attached along the front to the caissons. Modules were assembled into panels, and the panels were lifted by forklift onto the truss. After all panels were complete and installed, the truss was raised at the back and the rear support tubes put in place.
- The City of Austin, Texas, completed installation of a 17.9-kW IPC system which became operational on July 4. The system is located at the City of Austin Convention Center. Because of the disk/harness problems with IPC's Davis US-1 system (noted above), the MSEC modules were factory retrofitted with standard junction boxes.
- NYSERDA completed installation of a 20-kW IPC system at the Farmingdale campus of State University of New York. The MSEC modules were factory retrofitted with standard junction boxes. Although the PV system was completed in 1992, NYSERDA had not yet secured permission for grid interaction from the utility, the Long Island Lighting Company.

EMT-3

No construction activity occurred for the EMT-3 arrays.

US-2

- SSI was awarded the contract for the Kerman US-2 system in April. Due to permitting uncertainties, site construction activities were delayed three months until September, when a permitting exemption was granted by the County of Fresno. This exemption was granted after permitting jurisdiction for the site was clarified by the California Public Utilities Commission through an informal process. PG&E had conducted a geotechnical study in 1991 which found the site free of toxins and suitable for construction (see *1991 PVUSA Progress Report*). By year's end, construction and installation of the US system and all electrical equipment was nearly complete. The system was fully installed in the first quarter of 1993.

Section 3

FACTORY AND FIELD QUALIFICATION TESTS

This section describes the objectives and results of factory and field qualification tests, and summarizes the results of field wet resistance and performance testing.

OBJECTIVES

PVUSA has developed a set of factory and field qualification tests based on existing and proposed industry standards to ensure the safe operation and reliability of PV technologies supplied to the project. These qualification tests address durability and reliability, electrical performance, mechanical strength, safety, and corrosion resistance, and are likely to be offered as input for domestic standards. In addition to meeting the requirements of PVUSA, such qualification tests will also be necessary in the longer term to satisfy utilities that PV can be operated safely and reliably over lifetimes that are likely to exceed 20 years in most utility settings.

Principal tests and qualifying inspections include engineering review of system drawings, as-built inspection of modules, field wet resistance (wet megger) tests, field I-V curves, system functional checks (e.g., protective relays, breakers, controls), power quality tests, and performance test period power measurements. A schematic of the PVUSA factory module qualification test sequence is included in Appendix F. Results of factory qualification tests, field wet resistance tests, and performance tests are described below.

FACTORY QUALIFICATION TESTS

US-1

SSI's modules passed factory qualification tests in June 1990, and construction was completed at Davis in early 1991. Since then, system acceptance has been delayed by operational problems with the two 100-kW inverters. In April 1992, a reconfigured and rebuilt inverter was installed at Davis following a PVUSA design review, an independent design safety review, and witnessed factory testing. The inverter was repackaged into a large, free-standing enclosure which provides easier access, better maintainability, and improved safety for operators. Preliminary operational testing was sufficiently encouraging that SSI elected to rebuild the second inverter for delivery to PVUSA in early 1993.

APS's modules completed factory qualification tests in May with satisfactory results. APS requested and was granted a variance for portions of the factory qualification tests related to corrosion susceptibility. This test was designed to find defects in module encapsulation and edge seals in the form of leakage current. Due to the large size of the APS modules (5' by 2'6") and the volume resistivity of the large-area soda-lime cover glass, the PVUSA TRC changed to an area-related pass/fail criteria. Because glass resistivity drops significantly as temperature increases, the TRC also agreed to limit factory wet high-pot test conditions for the APS modules to 22°C (+/- 3°C). These changes did not compromise the intent of the test, and were expected to result in a safe and reliable design. The APS power conditioning unit (PCU) passed factory qualification tests in February 1992. A design safety review of the PCU was conducted by a PVUSA safety consultant who paid several visits to APS. The company furnished validation of cable sizes and made minor changes to the level of detail provided on their drawings. Safety signs were added, as were emergency stop push buttons for each inverter. Minor modifications to cable routings were made.

FIELD QUALIFICATION TESTS

As an evaluation of a system's insulation and as a supplementary test of the system's safety, PVUSA conducts a field wet resistance (wet megger) test on the entire array prior to system acceptance. PVUSA developed this test based on a similar Jet Propulsion Laboratory test. The PVUSA test checks the environmental seal of the installed PV modules and their interconnecting wiring and determines the level of array leakage current. Excessive leakage current can indicate a mechanism for corrosion, and, at extremes, can represent a shock hazard. The test has proven to be highly effective in detecting quality control problems in manufacturing and installation processes. In addition to the initial field wet resistance test, PVUSA periodically conducts this test on sections of each array to ensure safe, reliable operation and detect any deterioration in system components.

IPC's MSEC modules had innovative disk connectors and wiring harnesses in lieu of junction boxes. After difficulties passing field qualification tests and three types of failures (leakage through wire-to-harness interface and harness pinholes, leakage through cracked disks, and melting of harness/disk electrical terminations), IPC in mid-1992 proposed returning to the standard junction box design, and MSEC began field retrofitting the Davis modules. Completion of the retrofit and subsequent field wet resistance testing is scheduled for second quarter 1993. MSEC modules for IPC's NYSERDA array were factory retrofitted in 1992, as were the modules for the IPC Austin host system.

During 1992, field wet resistance tests were conducted for Sovonics (Davis), APS (Davis), and SSI (Kerman). Results are summarized below.

The test was performed on the Sovonics EMT-1 system at Davis in July as periodic maintenance. Four of 1200 modules failed. One module had a burned-through junction-box cover and was replaced; the other modules had loose or missing junction-box covers and were sealed with insulating compound. All four were retested and passed, and the system resumed operating at full power.

The test was conducted on the APS US-1 array as part of system acceptance testing. APS requested and was granted a variance regarding a temperature limit for field wet resistance tests. Because the volume resistivity of APS's large glass/glass modules decreases at higher temperatures, the TRC agreed to 35°C as the maximum acceptable glass temperature at which these tests could be conducted. Field wet resistance and I-V curve tests were conducted in July and August. Of 9600 modules, 27 had cracked glass and 46 had failed connectors; all failed modules and connectors were replaced. The APS panels are joined and brought to a common bus with a piercing connector. The connector had been qualified for use on automobile and marine engines, but had not been qualified for use in a PV system. Of the 960 connectors, 242 failed initial testing. APS injected and sealed all piercing connectors with an epoxy sealant as a temporary fix. All connectors then passed the testing. APS is now conducting accelerated aging tests to determine if the connectors, with epoxy, have a 20-year life expectancy.

The Kerman US-2 system was tested in December. Nine of the 12,240 modules failed and were replaced. Except for one module with an obvious cut backskin, the precise cause of failure was not identified. One bypass diode required replacement. Two shop-installed wire terminations required tightening. Replacement and retesting were completed in January 1993.

Once the field wet resistance tests have been completed and a system receives permission to operate in parallel with the PG&E grid, a short series of power quality tests is conducted. The tests determine if the system power factor, harmonic distortion, and phase current balance are within PG&E's specifications.

During 1992, power quality tests were conducted for the APS system. The system performed within the specified parameters. Test results appear in Table 3-1.

Table 3-1
1992 PVUSA Power Quality Tests on APS Davis System

Parameter	Required Values	APS's Values
Current		
THD ¹	$\leq 5\%$	3.8%
Any single harmonic	$\leq 3\%$	2.0%
Voltage		
THD	$\leq 3\%$	1.1%
Any single harmonic	$\leq 1\%$	— ²
Power factor	≥ 0.95 (lagging)	0.95 (leading)
dc current injection	$< 0.5\%$	0%
Phase current balance	$< 0.5\%$	0.2%

¹ Total harmonic distortion.

² No value.

PERFORMANCE TESTS

The final step in acceptance of an EMT or US system is a 30-day performance test period. During this time, data are gathered to determine the system rating.

To calculate the expected power from a PV system under PVUSA Test Conditions (PTC), PVUSA models PV power as a function of 1000 W/m² plane of array (POA) irradiance for flat-plate modules, 850 W/m² direct normal irradiance for concentrators, 20°C ambient temperature, and 1 m/s wind speed. The resulting power rating at PTC determines the payment that a supplier receives. If the PTC power rating is lower than the power rating in the supplier's bid, then payment is reduced proportionately. The PTC power rating is lower than power ratings at Standard Test Conditions (STC), defined as 1000 W/m² POA irradiance, 850 W/m² direct normal for concentrators, 25 or 28°C cell temperature, and air mass 1.5 spectrum, because during field operation the cell temperatures are ordinarily at least 20°C above the STC temperature.

The APS US-1 system was given a full performance test in 1992. Based on performance data collected during September and October, the system was rated at 479 kW PTC, 79 kW over the contracted power, and was accepted in December. The SSI and IPC US-1 systems had not yet been rated at the time of publication of this report. However, preliminary tests indicate that the IPC system will meet or exceed its contractually required power rating.

Section 4

SYSTEM PERFORMANCE AND MAINTENANCE

The following section discusses key performance areas for the PVUSA systems in operation during all or part of 1992: five EMT-1 arrays in Davis, California; one EMT-1 array in Maui, Hawaii; a US-1 system in Davis; and a US-1 host system at the City of Austin electric utility, Texas. It briefly describes the PVUSA data acquisition systems (DAS) at Davis and Kerman and data collection improvements under way during 1992; summarizes overall performance for the year; updates measures of performance such as energy production, efficiency, capacity factor, and availability; and describes O&M activities. Weather data that help characterize the Davis, Maui, and Austin sites are included in Appendix A.

DATA ACQUISITION AND ANALYSIS

PVUSA's DAS at Davis consists of a network of Campbell Scientific data loggers—one for each PV system, one for the solar/weather instruments, and one for utility grid monitoring. The data loggers for all but the US-1 PV systems monitor about two dozen channels with each data scan. For the US-1 systems, a greater number of similar channels are monitored, and expanded data loggers capable of scanning over 100 input signals are used.

The DAS monitors ac and dc voltage, current, and power; fault current; daily ac kWh; module and ambient temperature; plane of array (POA), horizontal, direct normal, and global normal irradiance; wind speed and direction; and rainfall. The PCU's on/off status, error off and recycle, and smoke alarms are also monitored.

Data channels are scanned every five seconds and averaged over 10 minutes. The data are relayed to a central computer (Data Acquisition Computer), which is responsible for system control. A second identical computer (Data Display Computer) is also employed to serve as a backup if the Data Acquisition Computer fails to perform complete data processing.

To speed analysis of data, a summary program is used to compile relevant performance statistics such as energy production, insolation, and meteorological information. The summary program can be run over any interval of days and for any number of PV systems.

PVUSA is evaluating the performance and capabilities of the DAS and upgrading the system to more effectively monitor current and future EMT and US installations. Work under way in 1992

included installation of a master database and conversion to Windows-based, object-oriented programming techniques. The system uses a Structured Query Language (SQL) to merge data from all project sites into a single database. SQL permits the user to develop ad hoc queries for studying aspects of the various systems' performance. (Fewer custom queries had been done in the past due to the large amount of time required to develop stand-alone processing software.) In addition, SQL allows various reporting functions to be automated with pull-down menus. The Windows environment makes possible the networking of Davis site computers and enhances the system's architectural flexibility.

Unlike the Davis systems, the Kerman US-2 installation will be linked to PG&E's Supervisory Control and Data Acquisition (SCADA) network. The SCADA system installed at Kerman site is a state-of-the-art, utility-grade system which facilitates integration of PV systems into the utility grid. A schematic of this system appears in Figure 4-1. The SCADA system allows remote operator functions as well as data acquisition and monitoring. Remote operator functions are performed from the Fresno Distribution Operator's office only.

The main SCADA unit located in the electrical room monitors a total of 130 data points from the 12-kV switchgear, two field units, and a meteorological station. The field units, which are located next to the PCUs and connected to the electrical room via fiber optic cable, monitor all dc and ac current and voltages as well as PCU status, POA irradiance, and array temperature. Total plant ac output (watts and VARs) is redundantly monitored via a Campbell Scientific data logger, which is also used to collect meteorological data. The main SCADA unit receives data from these sources and exports them to PG&E division operators in Fresno and to the PG&E Research and Development database computer at the Kerman site.

Data are transmitted to the Fresno office from the Kerman electrical building via the Bear Mountain receiver station using a 900-MHz radio link. The data are then transferred via modem to the Fresno SCADA system. Division operators are capable of remotely monitoring all system functions and site security, as well as starting, stopping, and resetting each PCU and opening or closing the 12-kV disconnect. The data are simultaneously made available to a database 486 computer located in the research trailer at the Kerman site. Using commercially available software, the database logs data from all points every five seconds, and then computes and stores 10-minute averages of these values. The averages are downloaded daily via a 14.4-kilobaud modem to the PVUSA project site in Davis, where they are analyzed with other host site data.

Figure 4-1
Kerman SCADA system diagram showing radio link to Fresno and simultaneous R&D data acquisition.

An additional feature of the Kerman SCADA system is that it allows O&M personnel to locally monitor system performance for troubleshooting purposes by plugging into the main SCADA unit with a laptop computer, which is also called the maintenance computer.

OVERALL PERFORMANCE

In 1992, PVUSA's installed operational capacity grew from 100 kW to nearly 600 kW. Combined, PVUSA's systems in Davis, Maui, and Austin generated 441,943 kWh, enough to satisfy the electricity requirements of about 70 homes, based on PG&E average residential customer load of about 500 kWh per month. The EMT-1 systems in Davis generated 111,091 kWh, the US-1 systems in Davis generated 299,640 kWh, the Maui EMT host site generated 28,085 kWh, and the Austin US host site generated 3,127 kWh (data collection for Austin began in November). Through 1992, PVUSA's various systems had generated a cumulative total of 900,476 kWh (see Figure 4-2). The millionth kWh milestone occurred in the first quarter of 1993 as new US systems at Kerman and Davis were brought on line.

Figure 4-2 shows how PVUSA's annual energy generation grew between 1989 and 1992. Tables 4-1A and 4-1B outline key features of each system. A four-year performance summary for these systems appears in Table 4-2. Detailed 1992 monthly summaries are included in Appendix B.

Figure 4-2
PVUSA Cumulative Energy Production In MWh

Table 4-1A
PVUSA Installed EMT Array Characteristics

	SSI	Sovonics <i>D=Davis</i> <i>M=Maul</i>	UPG	Solarex	ENTECH
Installation date	1/89	6/89 <i>D</i> 10/89 <i>M</i>	12/89	10/90	3/91
Orientation ¹	30° FFP	30° FFP <i>D</i> 22° FFP <i>M</i>	30° FFP	30° FFP	2-ax Trk
dc [ac] ratings (kW)	18.7 [18.1]	17.3 [15.9] <i>D</i> 18.5 [17.6] <i>M</i>	15.7 [15.1]	15.7 [15.1]	16.5 [15.6]
Number of modules	400	1200 <i>D,M</i>	4992	336	60
Module area (m ²)	169	497 <i>D,M</i>	477	182	172
Array/module area	1.01	1.02 <i>D,M</i>	1.03	1.15	2.09

¹ FFP = fixed flat plate
2-ax Trk = two-axis tracking

Table 4-1B
PVUSA Installed US System Characteristics

	APS	IPC Austin
Installation date	9/92	7/92
Orientation ¹	30° FFP	1-ax Trk
ac rating (kW)	479	17.9
Number of modules	9600	96
Module area (m ²)	11,520	212.1
Array/module area	1.16	1.05

¹ FFP = fixed flat plate
1-ax Trk = one-axis tracking, horizontal N-S axis

Table 4-2
PVUSA Annual Performance Summary¹

	System	1989	1990	1991	1992
ac Energy (kWh)	SSI	33,391	34,243	31,133	29,261
	Sovonics Davis	25,034	29,037	12,087	12,181
	Sovonics Maui	5,713	29,518	27,319	28,085
	UPG	4,559	29,349	25,823	25,407
	Solarex	n/i	4,715	26,016	22,767
	ENTECH	n/i	n/i	27,558	21,117
	APS	n/i	n/i	n/i	214,508
	IPC Austin	n/i	n/i	n/i	3,127
Efficiency (%)	SSI (dc)	10.7	10.6	10.4	10.1
	Sovonics Davis (dc)	3.3	3.1	2.9	2.8
	Sovonics Maui (dc)	3.7	3.7	3.4	3.4
	UPG (dc)	n/i	3.2	3.0	3.0
	Solarex (dc)	n/i	8.8	8.2	7.3
	ENTECH (dc) ²	n/i	n/i	11.2	10.7
	APS (ac)	n/i	n/i	n/i	3.8
	IPC Austin (ac)	n/i	n/i	n/i	8.5
ac Capacity Factor (%)	SSI	21.7	21.7	19.7	18.5
	Sovonics Davis	21.8	20.9	8.7	8.7
	Sovonics Maui	21.4	19.1	17.7	18.2
	UPG	n/i	22.3	19.5	19.2
	Solarex	n/i	17.8	19.7	17.2
	ENTECH ²	n/i	n/i	26.8	15.4
	APS	n/i	n/i	n/i	15.3
	IPC Austin	n/i	n/i	n/i	8.5
Availability (%) ³	SSI	n/r	83	80	81
	Sovonics Davis	n/r	80	35	37
	Sovonics Maui	n/r	74	71	73
	UPG	n/r	86	83	85
	Solarex	n/r	83	76	75
	ENTECH	n/r	n/i	69	46
	APS	n/r	n/i	n/i	80
	IPC Austin	n/r	n/i	n/i	73

¹ Start dates are staggered; therefore, some quantities are based on a partial year's performance. Refer to tables 4-1A and 4-1B for installation dates.

² ENTECH performance based on direct normal, not global plane-of-array insolation.

³ Availability defined as the percentage of daylight hours during which a system supplies net power to the grid. This quantity not measured in 1989.

n/i = not installed
n/r = not recorded

ELECTRICAL ENERGY PRODUCTION

Electrical energy production generally follows the trend in insolation, except that the electrical energy production also reflects outages, limited operation during installation and startup, and seasonal efficiency variations.

Figure 4-3 tracks the 1992 monthly ac energy generated by the five EMT systems in Davis. Figure 4-4 shows corresponding data for the three US systems in Davis. Figure 4-5 shows the 1992 monthly ac energy generated by the Maui Sovonics system, and for purposes of comparison, includes the Davis Sovonics ac energy generation and Davis site insolation. Data for the IPC Austin system are included in Table 4-2; December was the only full month that data were available.

Referenced to the right scale of these figures are lines showing POA insolation (this quantity includes all daylight hours—between sunrise and sunset) and the average insolation over the past few years. For Davis, the average is based on 1989 through 1992, and for Maui, the average is based on 1990 through 1992. The measured 30° tilt insolation for Davis was 4 percent less than the 1989 to 1992 average, and about 0.5 percent greater than the long-term average. The measured 22° tilt insolation for Maui was about 1 percent greater than the 1990 to 1992 average (long-term data are not available for the Maui site).

For Davis, the EMT energy production pattern varies fairly smoothly from a little under 1000 to over 3000 kWh per month, with a site average of 1850 kWh/month. There are a few notable deviations from the insolation trend line:

- The Sovonics array was out of service from June 1991 until July 1992, when a failed main dc junction box was replaced. In late 1992, the array's energy production began to dip out of proportion with the other arrays. While a small improvement has been observed so far in early 1993, PVUSA is still working on diagnosing the cause of the recent poor performance.
- The ENTECH concentrator array, which operates on direct normal insolation, exhibits poorer performance than the flat plate arrays during the cloudy winter months. Even on an annual basis, the direct normal insolation for 1992 was about 10 percent less than the global 30° tilt insolation used by the other EMT arrays. The ENTECH array also experienced significant downtime in March, June, and for much of the 4th quarter because of problems with the array tracker controller.
- The Solarex array lost one of its fourteen source circuits in mid-February when a junction box failed. The failure was discovered in mid-March, and the array was shut down for about two weeks. Another source circuit showing signs of impending junction box failure was disconnected, and the array ran at 12/14 power until mid-July, when all repairs were completed.

Figure 4-3
PVUSA Davis Generation and Insolation
1992 EMT Output

Figure 4-5
Sovonics Generation and Site Insolation
Davis and Maui, 1992

Of the Davis US systems shown in Figure 4-4, only the APS system was completed for full operation in 1992. The other two, IPC and SSI, were online for limited periods of startup and testing only. October was the first month of full operation for the APS system. From October through December, the generation and insolation trends match well, although it is evident from the relative height of the APS kWh bar and the 30° insolation line that as the year progressed the number of kWh generated per unit of insolation decreased. This anomaly is probably attributable to a large degree of shading on the APS system's pilot cell during the winter months. When shaded, the pilot cell prevents the PCU from starting and causes it to turn off prematurely. The result is a lowered availability, even though no failures have occurred. Although an initial drop in efficiency due to sunlight-induced amorphous silicon degradation is common, the system efficiency remained steady at 4.1 percent between October and December. Most of the modules may have already degraded to a more stable level during the four months between installation and full operation.

For the Maui site, there is no apparent seasonal trend in either the insolation or generation. Because of its low latitude, there is less fluctuation in day length than for the Davis site. The relatively flat monthly insolation pattern in 1992 was consistent with the 1990 to 1992 average. The fluctuations in generation are generally indicative of varying system availability.

Until late September, when an adjustment was made to the Maui system's PCU to widen its operating voltage range, numerous PCU trips (53 in the first nine months of the year) resulted in lowered energy production, especially when the trips occurred on weekends. After the adjustment was made, the PCU only tripped off line once through the end of the year. Five module failures occurred in 1992, compared to 11 in 1991 and 13 in 1990. Although the system can operate with failed modules, the overall array efficiency (and power) can drop by as much as 25 percent when operating with just two failed modules. Although less of a problem in 1992 than in past years, there were a few periods where the system operated for a week or more at a reduced output because of failed modules.

EFFICIENCY

Efficiency for all arrays except the ENTECH array is calculated as the ratio of monthly dc energy produced to monthly POA insolation during hours when the PCU is operating. The ENTECH array, which uses a 22x concentrating lens and two-axis tracking structure, partially shades itself and its pyrheliometer during the early and late hours of the day. Therefore, its efficiency calculations are based on data collected between 9 a.m. and 3 p.m. PST, when shading does not occur. Also, direct normal insolation is used, rather than POA.

Figure 4-6 shows monthly average dc efficiencies for the EMT arrays, and ac efficiencies for the US systems. Three groupings are apparent. The highest efficiency arrays, from SSI and ENTECH, have averaged 10 to 11 percent, with broad temperature-related seasonal swings. Both use single-crystal silicon PV cells.

The second grouping, at about 8 percent efficiency, includes the Solarex Davis and IPC Austin systems. Both use polycrystalline silicon PV cells, but the Solarex array is based on dc efficiency and the IPC Austin system is based on ac efficiency. As demonstrated by the Solarex array, there is a similar sensitivity to temperature as with the single-crystal types.

The lowest grouping includes all four of PVUSA's amorphous silicon arrays. The APS US-1 system's ac efficiency of about 4 percent is unexpectedly higher than any of the amorphous EMTs, which are clustered around 3 to 3.5 percent (dc). However, this system is new, and may drop closer to the others during its first year if it follows a typical amorphous silicon degradation pattern of 20 percent within 12 months.

The Sovonics EMT array at Davis was returned to service in July 1992, and operated for several months at an efficiency comparable to what it did before it went off line in June 1991 (due to an earlier-noted junction box failure). In November its efficiency began to drop at a faster rate than normally seen over the past few winters, but no failures were identified, even though it operated at an average efficiency of just 2.1 percent in December. A modest improvement has been seen so far in 1993, and PVUSA is working to identify whether failures have occurred.

CAPACITY FACTOR

Capacity factor is calculated as the ratio of monthly ac energy (kWh) divided by the product of the ac rating (kW) as determined by PVUSA and the number of hours per month.

Figure 4-7 details 1992 monthly capacity factors for the eight completed systems in Davis, Maui, and Austin. The trends are the same as observed for monthly generation, but are normalized to a dimensionless 0 to 1 scale. The 1992 annual average capacity factors ranged from 9 percent to 19 percent, with the large variation mostly related to system reliability.

Capacity factors over shorter time intervals can be much higher. Figure 4-8 illustrates the capacity factors for each array during PG&E's 1991 and 1992 peak periods (weekdays in May through October, 12 p.m. to 6 p.m.). Peak period capacity factors of 60 percent are typical for fixed arrays that face south, and capacity factors as high as 75 percent have been demonstrated for the two-axis tracking array.

Figure 4-7
 1992 PVUSA Capacity Factors
 Davis, Maui, and Austin Sites

Figure 4-8
 PVUSA Davis EMT Array Capacity Factors
 During PG&E's Summer On-Peak Hours

SYSTEM AVAILABILITY

System availability is defined by PVUSA as the percentage of daylight hours during which a system supplies net power to the utility grid. System-based availabilities are affected by the array orientation and system operating characteristics and reliability. Availability is also affected by poor weather, because at very low irradiance during cloudy daytime hours, power output may drop below zero due to internal system power requirements.

Figure 4-9 charts availabilities for the eight systems during 1990 through 1992. (No data are available for 1989.) System availability has typically ranged between 60 to 90 percent, except for the Sovonics and ENTECH systems at Davis. The Sovonics system was out of operation from late June 1991 until July 1992 due to a failed main source circuit junction box. The ENTECH array has experienced chronic tracker controller problems that sharply reduced the system's availability during the early and late months of 1992.

System availability calculations are sensitive to the amount of time during which array power is not high enough to overcome the PCU's internal load (about 0.4 kW for the EMT DECC PCU). During the hours near sunrise and sunset, the irradiance and PCU efficiency are often too low to produce net power output. Also, arrays with higher ratings can be expected to exceed the PCU's minimum requirements at lower irradiance levels than arrays with low ratings. However, the amount of unused potential energy during the sunrise and sunset hours is small—typically, less than 2 percent of the total daily insolation. Therefore, availability as defined here is a conservative number.

OPERATION AND MAINTENANCE

One of PVUSA's objectives is to assess the O&M requirements of PV systems within an electric utility setting. Work began in 1992 to develop an O&M database and to enter data from written records of EMT-1 O&M activities. The new database will allow PVUSA to standardize O&M data collection, minimize data omissions, and calculate O&M costs. Experience gained in developing the new system using EMT data will be used to establish an O&M database for the US systems.

A summary of the major 1992 O&M activities for the five EMT-1 arrays at Davis, the EMT-1 array in Maui, the Davis US-1 system, the City of Austin US-1 system, and the PCUs appears below. Chronological lists of preventive, failure-related, and research O&M activities during 1992 are shown in Appendix C.

Figure 4-9
PVUSA Daylight System Availabilities

EMT-1

SSI

- The manufacturer temporarily switched out 10 modules to analyze their integrity after three and a half years of operation.

Sovonics Davis

- The array was non-operational from June 1991 to July 1992, due to a dc source circuit combiner junction box fire. A new box was fabricated and installed in July, and an underground cable fault was identified and the cable replaced.
- Five of 1200 modules showing evidence of delamination (bubbles up to about three inches in diameter) were identified. Replacement modules are no longer available. The present modules are electrically sound and will continue to be used.
- One module junction box failed, and the module was replaced.

Sovonics Maul

- The array tripped off line and had to be reset manually 54 times. Some of these trips were attributable to system disturbances but a growing number were indicated as dc overvoltages. Adjustment of the PCU's dc operating voltage settings nearly eliminated the problem.
- Five modules were replaced due to junction box wiring failures. (Eleven modules were replaced in 1991 and 13 were replaced in 1990, all with the same failure.)
- The data logger unit was replaced because of suspected inaccuracies in its temperature measurements. The internal temperature sensor of the original unit was checked and found to be accurate. Temperature readings of the new data logger are consistent with those of the original. The source of the problem has not yet been identified.
- Several modules showed minor delamination problems.

UPG

- One of 4992 modules was replaced in 1992 due to shattered cover glass of unknown cause.

Solarex

- Water intrusion and subsequent corrosion damaged one source circuit junction box and triggered an explosive failure of another; two of 14 circuits were lost. Changes to the cable entry locations were made for all of the junction boxes to avoid similar failures; the two damaged boxes were repaired.

ENTECH

- The tracker controller failed five times. The roll motor, battery, control board, charger, power supply, and controller were replaced. The replacement tracker control board failed, possibly due to lightning. The board was repaired and modified to guard against similar failures.
- The wind speed sensor in the new tracker control board failed, rendering the high wind stow signal inoperative and requiring manual shut down in the stow position during high winds and on holidays.

EMT PCUs

- The PCU connected to the SSI array experienced three synchronization errors. The PCU connected to the UPG array experienced 14 synchronization errors. The PCU connected to the Solarex array experienced one error, and the PCU connected to the ENTECH array experienced two errors. In each case, a manual reset was initiated and restored operation.
- The PCUs connected to the UPG and Solarex arrays each experienced one frequency error. Manual resets were required to restart each PCU.
- The PCU connected to the ENTECH array blew a dc contactor fuse; the failed 2-amp fuse was replaced.

US-1

SSI

- The SSI tracking system was modified in an attempt to get operational data. SSI installed an actuator with a different refrigerant for test and comparison purposes.

APS

- As a result of periods of estimated 40 to 50 mph winds, glass breakage occurred on eight modules and several panels were loosened. All damaged modules were replaced and all fastenings re-torqued and sealed with "Locktite." No further problems were experienced. The number of failures was lower than anticipated. Failures are believed to be of a quality control nature, and were not attributable to a design flaw.
- Visible blemishes of unknown cause were detected on a number of modules. These blemishes include worm-like tracks, fern-like patterns, and burn spots believed to have occurred during manufacture and which have not progressed notably since installation. As there are 9600 modules in the array field, the blemishes are not considered statistically significant, nor did they contribute to any noticeable decline in 1992 system performance. However, these phenomena will be monitored for longer-term effects.
- Two broken modules were replaced.
- In November, APS made a software change because the inverters required manual reset each morning. The change restored fully automatic operation and no further manual resets were required.

IPC (Austin Host System)

- An inverter fuse blew due to a fire in the DAS boxes, which was caused by unprotected transducers; the fuse was replaced. A faulty transducer was also identified and replaced.
- During array acceptance testing, a short circuit current fire began in the dc disconnect boxes in the mechanical room. The fire was caused by inappropriate testing procedures.

Section 5

OTHER ACTIVITIES

This section describes 1992 activities in the areas of project planning and technology transfer. It also discusses 1992 safety efforts.

PVUSA PROJECT PLAN

In an effort to assure proper implementation of PVUSA's goals and objectives and define the type of data that will be necessary to meet them, the project team began formalizing the comprehensive PVUSA project plan. The purpose of this plan is to provide a road map and establish the boundary conditions for the PVUSA project. The plan will include sections on construction, engineering and design, data acquisition and analysis, BOS costs, O&M, and technology transfer for the Davis, Kerman, and host sites. Long-term operation of the Davis and Kerman sites is also addressed. The plan will be reviewed by the PVUSA TRC and SC and is to be completed in 1993.

KERMAN PROJECT PLAN

PVUSA staff completed the Kerman Project Plan, which describes project objectives, potential distributed and system benefits, O&M documentation methods, and validation activities for testing the accuracy of existing PV performance planning models. The plan describes evaluation methods for testing the PV grid-support hypothesis and prioritizes research activities using a four-part criteria. The plan was completed with input from internal PG&E experts on utility electrical systems as well as with input from the SC and TRC. (It is available through the PVUSA project office.)

TECHNOLOGY TRANSFER ACTIVITIES

PVUSA project staff developed a technology transfer plan. The goals of the plan are to establish a strategy for providing PVUSA information to PG&E, other utilities, and the PV industry; to encourage utility and public acceptance of PV; and to solicit utility participants for hands-on PV experience. In July the plan was submitted to PG&E for approval as a working document.

In 1992, PVUSA also began developing a Design Basis Document delineating engineering criteria used for the Kerman US-2 installation. The document provides the engineering bases for design, construction, installation, and operation of a large-scale PV system, built to PG&E substation criteria. It is expected to be valuable to other utilities installing PV systems of 100 kW or larger.

Lessons learned at PVUSA continue to be applied to standards development work. Many of the module qualification and system acceptance procedures used in PVUSA procurements are furnishing input into standards in the domestic and international arenas.

SAFETY PLANNING

Significant effort continued in 1992 to ensure enhanced safety at the PVUSA sites. Meetings began in January to enhance the site safety program and to respond to concerns raised during a DOE safety review held in late 1991. An internal safety committee was established to ensure that an appropriate safety program is in place and is implemented at the Davis and Kerman sites, and to provide a vehicle for resolving safety concerns of committee participants and other PVUSA project team members. The committee includes representatives from PG&E, Bechtel, and Endecon, and is chaired by the PVUSA project manager. Committee members began to develop an Illness and Injury Prevention Program and a Safety and Health Action Plan, which describes required emergency preparedness activities, training, hazard communication methods, first aid and medical procedures, accident investigation and reporting, and specific safety requirements for both the Kerman and Davis PVUSA sites. (This document is available through the PVUSA project office.) The PVUSA safety program helps provide a model for developing safety programs at other PV installations within the utility sector.

Section 6

KEY FINDINGS

PROCUREMENT AND CONSTRUCTION

A significant accomplishment in this area has been the rapid completion of the SSI US-2 system at Kerman. A contract was awarded to SSI in April; by December, the system was 85 percent complete. The rapid progress in construction of this system, which uses proven PV technologies, contrasts markedly with the ongoing delays experienced by the suppliers of more developmental EMT and US-1 components. Another milestone was the completion of the APS US-1 system in December at well over the target rating.

Manufacturing delays, module qualification difficulties, and PCU problems continued to slow completion of EMT and US systems at Davis. Most suppliers have underestimated the time and effort required to advance their technologies or production facilities to the point where the proposed module or system can be manufactured and installed. Many PV system suppliers also lack experience in system design and installation, or lack facilities to perform qualification tests. In addition, some schedules for module manufacture and delivery were delayed by the inability of the modules to pass PVUSA's rigorous qualification tests. As a result, completion of the EMT-2 systems and the remaining US-1 systems, originally targeted for late 1990, is expected to be delayed until mid-1993.

ENGINEERING

Vendors have experienced problems with unproven system components, indicative of risks associated with new technological development. For example, full startup for the IPC US-1 system was delayed due to problems with the new and innovative module termination discs and wiring harnesses on MSEC's new modules. The manufacturer is retrofitting the modules in the field with conventional junction boxes. Further development is required for the Dickerson inverters. Also, failures associated with the Solarex combiner junction boxes resulted in design-related modifications.

In order to capture important information regarding the non-PV aspects of the Kerman project, a design basis document is necessary. As a result, the design criteria documents which detail the electrical and civil engineering bases for the US system at Kerman are valuable products for PVUSA.

PERFORMANCE

Over the first few months of operation, the APS system efficiency has averaged about 4 percent, with degradation typical of amorphous technology. It is not clear whether various phenomena detected in APS modules will become significant in terms of efficiency, reliability, or safety. As a result, it is important that they continue to be monitored.

In general, both module and overall system reliability have been good for the EMT arrays. There have been no module failures for either the Solarex or ENTECH arrays, each of which has been operating for over two years. EMT efficiency trends remained as expected, with the exception of an unanticipated slow decrease in the efficiency of the SSI crystalline silicon array.

Annual capacity factors for fixed-tilt arrays operating at Davis ranged from 9 percent to 19 percent, with the large variation related mostly to system reliability. Typical capacity factors for "healthy" arrays were about 20 percent in 1991. The drop in 1992 is largely a result of a 4 percent decrease in insolation for the fixed-tilt arrays compared to 1991. Capacity factors were over 60 percent during PG&E's summer on-peak hours (weekdays, noon to 6:00 p.m.).

EMT-1 system availability ranged from 60 to 90 percent, excluding the Sovonics and ENTECH systems which were out of operation for periods of the year. Winter availabilities for the Davis systems have typically been lower than during other seasons, because the Davis site tends to have long periods of heavily overcast skies or rain.

OPERATION AND MAINTENANCE

The computerized O&M database developed in 1992 will help PVUSA standardize O&M data collection, more accurately track O&M activities, and analyze EMT-1 (and later, US) O&M costs. Database development was an important activity in that it provided a "dry run" for the larger US systems coming on line.

The EMT-1 flat plate arrays continued to require moderate maintenance and repairs and have not exhibited high maintenance, as may have been expected in such a first-of-its-kind field test. According to the manufacturer, problems with the ENTECH tracker controller board have not occurred at other ENTECH installations and are not considered relevant for extrapolations of expected performance of larger ENTECH arrays.

TECHNOLOGY TRANSFER

Domestic and international interest in the PVUSA project remains strong. The Davis facility hosted tours for about 600 visitors representing 20 countries, and PVUSA project team members were invited to participate at a number of technical conferences. Lessons learned at PVUSA continue to be applied to standards development work at the Institute of Electrical and Electronics Engineers, Inc. (IEEE) and the International Electrotechnical Commission (IEC).

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

1. Schedule slippages for the EMT and US systems continue. Vendors have been overly optimistic in their proposed schedules; the technical and financial challenges involved in bringing innovative module technologies out of development and into the field have caused significant, unanticipated delays. Also, the stringent but necessary requirements of PVUSA qualification tests, which play a key role in ensuring module and system reliability, have contributed significantly to schedule revisions.
2. Kerman US-2 has been the most timely of all PVUSA installations; the 500-kW system was substantially completed just nine months after the contract was awarded. Unlike the EMT and US-1 systems, the Kerman installation uses more proven components. Thus, this experience is a much better indicator of the construction schedule expected from a utility-scale PV installation.
3. While commercialization of exact replicas of PVUSA's EMT technologies is unlikely, lessons learned from the project have helped to build a database for monitoring array component performance and are useful for "next generation" technology advances.
4. Suppliers need a place to field test their technologies. Suppliers must also be ready to clearly demonstrate compliance with 20- to 30-year design life standards. Attention to detail in design is critical; lack thereof can result in costly field retrofits. However, without field demonstration of new products and designs, progress will slow.
5. Documentation of results to date is critical, but even more important is operational experience with the larger-scale systems to develop a database on equipment, performance, longevity, and O&M requirements.

FUTURE WORK

1. The focus of PVUSA will shift from procurement and installation of EMT and US systems to data collection, monitoring, and analysis of EMT and US systems. As a result, the data management and technology transfer components of the project will become more essential.
2. PVUSA provides an opportunity to analyze utility-scale BOS lessons learned and make BOS cost projections. In 1993 and 1994, PVUSA will analyze and report the true BOS costs for Davis and Kerman US systems, based on data provided by PVUSA and willing vendors. Similarly, O&M procedures and costs will be continually developed, evaluated, and updated.
3. Validation work for the Kerman US-2 installation will begin in 1993. PVUSA will validate initial analytical results, test assumptions used in justifying the installation, and draw insights that would apply to other T&D systems and other PV installations located in those systems. In addition, PVUSA will try to differentiate the technical and economic benefits that result from the installation.
4. The Design Basis Documents for Kerman, which contain electrical and civil engineering bases for a utility-scale PV installation based on PG&E substation standards, will be completed in 1993 and made available to participating utilities.
5. Reports on PVUSA system procurement, construction, performance rating methods, O&M, power quality issues, and safety are also planned.
6. PVUSA will work with the Utility Photovoltaics Group (UPVG) and Photovoltaics for Utilities (PV4U) on commercialization strategies for PV technologies.

Appendix A WEATHER DATA

Table A-1 compares 1989 through 1992 totals for several weather characteristics at the Davis site. Table A-2 compares 1990 through 1992 totals for the Maui site. A similar table has not been prepared for the Austin site because the Austin system was completed in July, but the DAS was not completed until mid-November; therefore only one month of data was recorded in 1992. Table A-3 shows 1992 weather data for the City of Austin site. Detailed 1992 monthly weather and performance summaries for all three sites are included in Appendix B. (Because of data logger input limitations, fewer quantities are measured at the Maui and Austin sites.)

**Table A-1
PVUSA Davis Weather Summary**

	1992	1991	1990	1989
Insolation, kWh/m ²				
Global horizontal (long-term = 1838)	1827	1877	1890	1812
Global 30° tilt	2038	2123	2213	2104
1-axis tracking (horz. N-S axis)	2498	2707	n/a	n/a
Global normal	2819	3044	3185	2982
Direct normal	1839	2260	2509	2189
Average T _{ambient} , °C (long-term = 15°C)	16.3	15.6	15.7	14.9
Minimum T _{ambient} , °C	-2.9	-6.0	-9.7	-6.4
Maximum T _{ambient} , °C	41.7	43.8	42.7	43.7
Average wind speed, m/s	3.0	3.2	3.2	2.9
Maximum wind speed, m/s	15.1	14.1	13.7	17.5
Rainfall, inches	19.7	11	13	13

Table A-2
PVUSA Maui Weather Summary

	1992	1991	1990
Insolation, kWh/m ²			
Global horizontal (long-term average n/a)	2070	2075	2122
Global 22° tilt	2148	2158	2078
Average T _{ambient} , °C	28.2	28.0	28.0
Minimum T _{ambient} , °C	15.7	17.0	15.8
Maximum T _{ambient} , °C	42.7	42.4	44.0
Average wind speed, m/s	3.7	3.5	3.0
Maximum wind speed, m/s	13.3	14.0	14.7

Table A-3
PVUSA Austin Weather Summary

	December 1992
Insolation, kWh/m ²	
Global horizontal (long-term average = 81)	54
1-axis tracking (horz. N-S axis)	65
Average T _{ambient} , °C	14.5
Minimum T _{ambient} , °C	2.8
Maximum T _{ambient} , °C	29.7
Average wind speed, m/s	1.5
Maximum wind speed, m/s	6.9

Figure A-1 shows the monthly insolation during 1992 at the Davis site for five orientations: global horizontal, global 30° tilt, global normal, direct normal, and global north-south single-axis.

Relative to the highest annual quantity, global normal, the next best orientation was the global-single axis, which received 89 percent of the global normal insolation. Direct normal insolation was 65 percent of the global normal, global 30° tilt insolation was 72 percent, and the global horizontal was 65 percent.

The global 30° tilt insolation showed the smallest seasonal variation. Single-axis insolation had a wide seasonal variation. During the summer it received nearly as much insolation as the global normal, but in the winter it approached the global horizontal insolation. The horizontal orientation received its highest insolation during the summer months, even surpassing the 30° tilt, because the solar incidence angles are smaller on the horizontal surface during summer. During the winter the incidence angles are always high (at least 60°), the days are short (9.3 hours as opposed to 14.6 hours in the summer), and horizontal surfaces receive much less insolation.

Much of Davis' rainfall occurs during the winter months, and there are often prolonged periods with heavy fog. The amount of insolation on any orientation, especially direct normal, is reduced greatly during overcast periods.

1992 monthly POA insolation data for the Maui site are shown in Figure 4-2, along with the Maui site's monthly energy production. Although the annual insolation for the fixed 30° tilt in Davis has been nearly the same as the annual insolation for the 22° tilt or horizontal orientations in Maui, the seasonal variation in insolation (especially for the 22° tilt) has been smaller at Maui. Seasonal variations of day length are reduced as latitude approaches the equator. Additionally, site weather characteristics at Maui tend to be less seasonally dependent. For the Maui site in 1992, the month with the highest insolation was only 13 percent higher than the average monthly insolation over the past three years. The worst month was only 10 percent less than the three-year monthly average. At Davis, the best month in 1992 was 35 percent above the four-year average, and the worst month was 63 percent less than the four-year average.

The average wind speeds are similar for the Davis and Maui sites. The average temperatures have been more than 22°F higher in Maui than in Davis, although the maximum temperatures have been similar.

Appendix B

DETAILED MONTHLY WEATHER AND PERFORMANCE SUMMARIES

Tables B-1 through B-3 contain detailed month-by-month data on solar resource, site weather, and system performance for the PVUSA Davis, California, site. Tables B-4 through B-6 contain similar data for the PVUSA Maui, Hawaii site. Tables B-7 through B-9 contain similar data for the PVUSA Austin, Texas, site. (Fewer quantities are measured at the Maui and Austin sites.)

Array and system efficiencies are based on the module area times the number of modules in the system. System availability is defined by PVUSA as the percentage of daylight hours during which the system supplies net power to the utility grid.

Filtered and unfiltered solar resource data are listed for the Davis site. Filtered measurements include wavelengths of solar radiation between 780 nanometers (nm) and 3000 nm. Filtered pyranometer domes were installed in 1989 and are due for replacement in 1993. Unfiltered measurements are based on wavelengths between 300 nm and 3000 nm. The ratio of filtered to unfiltered radiation can be used to infer atmospheric water vapor concentration, because significant water vapor absorption bands exist at wavelengths greater than 780 nm (infrared).

Table B-1
1992 PVUSA Davis Solar Resource Data

1992 Month	Global Normal				Global 30° Tilt				Global Horizontal				Direct Normal				Global 1-Axis Tracking
	Peak Irradiance (W/m ²)		Insolation (kWh/m ²)		Peak Irradiance (W/m ²)		Insolation (kWh/m ²)		Peak Irradiance (W/m ²)		Insolation (kWh/m ²)		Peak Irradiance (W/m ²)		Insolation (kWh/m ²)		Insolation (kWh/m ²)
	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered
January	1083	487	76.7	34.2	906	397	64.8	27.1	642	264	47.1	17.7	766	243	40.3	14.2	57.6
February	1157	470	131.4	56.5	1099	449	106.0	43.2	831	315	80.5	29.8	841	266	73.6	24.1	104.1
March	1214	501	187.2	81.4	1192	476	153.5	61.0	1005	370	131.6	48.4	827	238	96.1	27.8	163.2
April	1201	473	259.8	107.1	1169	455	197.6	78.5	1080	395	185.8	69.2	928	248	156.6	40.8	240.3
May	1170	463	347.4	141.6	1088	431	238.5	92.8	1094	401	245.1	91.2	881	285	202.3	57.7	330.1
June	1165	457	322.5	129.5	1127	441	216.4	83.0	1142	426	233.1	87.3	883	288	206.3	65.0	308.0
July	1158	452	359.9	146.9	1086	426	237.0	91.1	1090	401	250.1	93.1	946	302	251.7	76.5	346.1
August	1150	465	331.9	140.0	1142	460	234.3	91.9	1048	387	224.9	83.6	922	266	247.8	68.6	316.2
September	1137	457	301.6	124.7	1134	444	215.5	85.7	964	365	179.2	69.2	896	217	226.0	55.7	264.2
October	1107	450	224.5	93.4	1068	408	168.2	67.1	815	303	121.2	46.2	879	214	155.3	39.2	180.7
November	1100	458	181.6	78.1	1015	398	132.7	55.5	705	255	81.9	31.5	868	236	126.9	36.2	125.5
December	1200	497	94.4	41.4	872	377	73.4	30.1	565	241	46.8	17.4	831	234	56.0	15.3	62.5

B-2

Table B-2
1992 PVUSA Davis Weather Data

Month	Ambient Temperature (°C)			Wind Speed (m/s)		Precipitation	
	Min.	Avg.	Max.	Avg.	Max.	Total (In/month)	Max. (In/day)
January	-2.0	5.5	13.5	2.4	11.7	1.55	0.4
February	-0.1	11.8	23.3	3.3	12.1	6.44	1.07
March	4.7	13.0	25.3	2.7	9.0	2.79	1.02
April	3.4	16.4	32.5	2.9	13.8	0.6	0.42
May	7.8	21.4	36.7	3.2	15.0	0.0	0.0
June	8.8	21.7	40.3	3.2	9.0	0.3	0.2
July	9.3	23.6	39.6	3.1	9.8	0.0	0.0
August	10.0	24.3	41.7	2.8	11.1	0.0	0.0
September	6.6	21.9	36.7	3.0	15.1	0.0	0.0
October	7.0	18.5	35.0	2.7	11.4	1.55	1.29
November	-0.8	11.6	24.8	3.2	13.8	0.3	0.08
December	-2.9	6.3	16.2	3.9	13.7	6.2	1.11
Annual	-2.9	16.3	41.7	3.0	15.1	19.73	1.29

Table B-3
1992 PVUSA Davis Performance Data

Month	System	T Mod. Wt. Avg. ¹ (°C)	POA Insol. (kWh/m ²)	dc Energy (kWh)	dc Eff. (%)	Max dc Power (kW)	ac Energy (kWh)	Max ac Power (kW)	System Avail. (%)
January	SSI EMT-1 Sovonics ²	20.5	63	1182	11.2	16.4	957	15.3	68
	UPG	22.2	62	902	3.1	11.7	803	11.3	79
	Solarex	20.0	61	974	8.7	13.9	784	13.2	61
	ENTECH	30.5	27	586	12.5	16.9	548	16.1	20
February	SSI EMT-1 Sovonics ²	29.4	105	1943	11.0	19.7	1676	18.5	79
	UPG	32.7	98	1417	3.0	14.8	1311	14.3	78
	Solarex	29.2	97	1479	8.4	15.9	1275	15.2	70
	ENTECH	32.3	26	555	12.6	17.9	515	17.0	19
March	SSI EMT-1 Sovonics ²	32.0	153	2798	10.8	20.8	2459	19.5	85
	UPG	35.5	139	2002	3.0	16.0	1864	15.2	83
	Solarex	34.0	99	1379	7.7	16.3	1215	15.6	50
	ENTECH	41.7	52	1079	12.0	17.0	1002	16.2	30
April	SSI EMT-1 Sovonics ²	39.1	198	3476	10.4	20.0	3097	18.6	85
	UPG	41.9	182	2559	3.0	15.5	2406	14.8	82
	Solarex	38.4	188	2448	7.2	14.4	2169	13.7	79
	ENTECH	46.2	140	2766	11.5	19.9	2576	18.9	68
May	SSI EMT-1 Sovonics ²	44.6	221	3663	9.8	18.5	3266	17.3	80
	UPG	47.1	231	3227	2.9	14.7	3040	14.1	89
	Solarex	44.6	232	2836	6.7	13.4	2517	12.7	82
	ENTECH	51.4	199	3754	11.0	17.3	3499	16.4	80
June	SSI EMT-1 Sovonics ²	45.1	212	3528	9.8	19.8	3116	18.5	83
	UPG	45.7	186	2659	3.0	15.7	2491	15.1	80
	Solarex	44.8	209	2552	6.7	14.6	2234	13.9	78
	ENTECH	50.6	85	1484	10.1	15.5	1375	14.6	34

¹ Average module temperature, weighted with respect to system power.

² Out until July 1992.

Table B-3
1992 PVUSA Davis Performance Data
(Cont'd)

Month	System	T Mod. Wt. Avg. ¹ (°C)	POA Insol. (kWh/m ²)	dc Energy (kWh)	dc Eff. (%)	Max dc Power (kW)	ac Energy (kWh)	Max ac Power (kW)	System Avail. (%)
July	SSI EMT-1	49.4	217	3563	9.7	18.2	3181	16.9	75
	Sovonics	50.4	200	2923	2.9	17.4	2564	15.9	67
	UPG	50.2	231	3340	3.0	15.6	3148	15.0	89
	Solarex	48.7	235	2983	7.0	15.0	2672	14.4	80
	ENTECH	56.7	212	4022	11.0	17.1	3762	16.2	77
August	SSI EMT-1	50.2	224	3528	9.3	18.0	3147	16.8	82
	Sovonics	50.9	220	3238	3.0	16.5	2846	15.1	79
	UPG	52.1	224	3115	2.9	15.1	2938	14.5	88
	Solarex	49.8	225	2981	7.3	15.3	2696	14.6	81
	ENTECH	56.3	211	3587	9.8	15.7	3355	14.8	78
September	SSI EMT-1	45.1	215	3275	9.0	17.8	2923	16.6	89
	Sovonics	45.8	216	2883	2.7	15.9	2533	14.5	85
	UPG	48.2	200	2632	2.8	14.8	2485	14.3	88
	Solarex	45.1	216	2773	7.1	15.1	2505	14.4	87
	ENTECH	44.4	193	3115	9.4	14.9	2905	14.1	81
October	SSI EMT-1	39.8	166	2830	10.1	17.4	2505	16.2	88
	Sovonics	40.5	166	2388	2.9	15.9	2102	14.5	80
	UPG	43.0	165	2416	3.1	14.6	2273	14.1	94
	Solarex	39.9	168	2379	7.8	15.0	2127	14.3	85
	ENTECH	45.1	20	407	11.6	16.2	374	15.4	14
	APS ²	41.8	146	--	--	--	68814	481.8	84
November	SSI EMT-1	27.9	132	2444	11.0	17.6	2167	16.4	87
	Sovonics	29.5	129	1667	2.6	15.5	1485	14.1	77
	UPG	32.6	128	1835	3.0	14.6	1722	14.1	91
	Solarex	28.6	134	1919	7.9	14.0	1703	13.3	83
	ENTECH	36.3	55	1118	11.7	17.4	1049	16.6	35
	APS ²	30.7	110	--	--	--	52094	475.6	83
December	SSI EMT-1	18.0	71	1350	11.2	16.5	1128	15.4	67
	Sovonics	22.5	69	724	2.1	11.9	649	10.8	50
	UPG	22.2	72	1023	3.0	12.0	925	11.6	81
	Solarex	21.0	73	1056	8.0	13.1	871	12.4	59
	ENTECH	25.0	8	169	11.8	15.3	156	14.6	7
	APS ²	23.0	57	--	--	--	26840	371.7	71

¹ Average module temperature, weighted with respect to system power.

² dc information is not reported for Utility Scale systems, i.e., APS.

Table B-4
1992 PVUSA Maui Solar Resource Data

1992 Month	Global 22° Tilt		Global Horizontal	
	Peak Irradiance (W/m ²)	Insolation (kWh/m ²)	Peak Irradiance (W/m ²)	Insolation (kWh/m ²)
January	1109	180	915	140
February	1238	172	1128	145
March	1201	200	1160	187
April	1224	197	1236	204
May	1115	187	1194	208
June	1116	178	1221	207
July	1199	174	1281	199
August	1179	182	1247	193
September	1194	183	1165	177
October	1193	172	1106	154
November	1172	159	982	130
December	1133	162	919	126

Table B-5
1992 PVUSA Maui Weather Data

1992 Month	Ambient Temperature (°C)			Wind Speed (m/s)	
	Min.	Avg.	Max.	Avg.	Max.
January	16.8	25.8	35.9	3.8	11.8
February	15.7	26.0	36.9	4.9	13.3
March	16.9	26.4	37.6	3.6	11.9
April	18.0	27.2	38.1	3.6	10.3
May	18.4	28.2	39.9	4.1	12.7
June	21.3	29.7	41.2	3.5	10.8
July	21.2	29.7	41.8	3.9	10.7
August	21.5	30.5	42.7	3.1	10.9
September	21.1	30.3	40.8	3.9	13.1
October	19.8	29.4	41.8	3.1	8.7
November	20.1	27.9	39.4	3.7	12.6
December	17.8	26.9	37.6	3.0	12.5

Table B-6
1992 PVUSA Maui Sononics
Performance Data

Month	T Mod. Wt. Avg. ¹ (°C)	POA Insol. (kWh/m ²)	dc Energy (kWh)	dc Eff. (%)	Max dc Power (kW)	ac Energy (kWh)	Max ac Power (kW)	System Avail. (%)
January	43.2	156	2669	3.4	18.3	2481	17.3	77
February	41.0	160	2704	3.4	19.8	2509	18.7	81
March	43.6	145	2527	3.5	19.6	2343	18.5	65
April	43.7	178	3020	3.4	19.1	2797	18.0	81
May	42.3	160	2462	3.1	18.4	2264	17.0	73
June	45.1	115	1976	3.5	17.7	1821	16.7	56
July	43.9	136	2310	3.4	20.0	2123	18.6	68
August	47.9	130	2119	3.3	18.9	1953	17.8	60
September	43.7	146	2468	3.4	20.0	2284	18.6	69
October	46.3	172	2944	3.4	19.1	2718	17.8	88
November	43.7	159	2732	3.5	19.4	2532	18.1	84
December	46.0	156	2444	3.2	18.1	2259	16.9	82

¹ Average module temperature, weighted with respect to system power.

Table B-7
1992 PVUSA Austin Solar Resource Data
(December Only)

1992 Month	Global Single-Axis Tracking		Global Horizontal	
	Peak Irradiance (W/m ²)	Insolation (kWh/m ²)	Peak Irradiance (W/m ²)	Insolation (kWh/m ²)
December	836	65	703	54

Table B-8
1992 PVUSA Austin Weather Data
(December Only)

1992 Month	Ambient Temperature (°C)			Wind Speed (m/s)	
	Min.	Avg.	Max.	Avg.	Max.
December	2.8	14.5	29.7	1.5	6.9

Table B-9
1992 PVUSA Austin IPC
Performance Data
(December Only)

Month	T Mod. Wt. Avg. ¹ (°C)	POA Insol. (kWh/m ²)	dc Energy (kWh)	dc Eff. (%)	Max dc Power (kW)	ac Energy (kWh)	Max ac Power (kW)	System Avail. (%)
December	27.0	64	--	--	--	1110	16.2	73

¹ Average module temperature, weighted with respect to system power.

Appendix C
DETAILED 1992 O&M SUMMARIES

Tables C-1 through C-3 summarize PVUSA's major O&M activities in 1992 at Davis. Table C-4 summarizes major O&M activities in 1992 for the host sites. (Some activities, such as washing arrays, do not interrupt plant performance.) The activities are defined as:

- Preventive maintenance (including planned outages)
- Failure-related (including forced outages)
- Research

Table C-1
1992 PVUSA Davis Preventive Maintenance

Event	Date; Duration
Meter readings: 480-V and 12-kV in/out meters. Report readings to PG&E Power Control Department	Monthly; 1/2 hr ea.
12-kV line opened: grounding demonstration	1/16; 2 hrs
PG&E distribution line work	1/20; 8 hrs
IPC clearance	2/7; 3 hrs
SSI US-1 clearance	3/12; 3 wks (switch failure)
Visual inspection of arrays: front, back and wiring	Monthly; 1 hr
ENTECH tracker clock, module position, NIP alignment, and stow battery inspection	Monthly; 1-2 hrs ea.
ENTECH tracker clock reset	4/22, 6/2, 8/28; 1/4 hr ea.

Table C-2
1992 PVUSA Davis Failure-Related Activities

Event	Date; Duration
PCU synchronization/frequency errors: SSI EMT-1 5/30, 7/10, 8/5; UPG 2/7-10, 3/28, 4/2, 4/15, 5/7, 5/12, 6/13, 6/19, 6/20, 6/21*, 7/4, 8/17, 8/19, 8/25, 11/18; Solarex 2/20*, 6/21; ENTECH 3/23, 10/28 (* = frequency errors)	Various dates; 1/2 hr to 3 days
12-kV interrupter switch repaired—was out of service since failure on 3/13	4/1; 4 hrs
Three unscheduled site power outages; systems tripped off-line	1/21; momentary 4/27; 1-1/2 hrs 8/23; 1-1/2 hrs
SSI EMT-1: no failures	
Sovonics: <ul style="list-style-type: none"> • five delaminating modules identified • new junction box delivered • inspections, drawings, and field modifications for junction box installation • new source circuit junction box installed and underground cable fault identified and replaced • ground fault caused by slight contact between negative bus and ground identified, cable re-routed • module which failed on 7/14 identified and replaced (including I-V curves), array remained in operation • smoke alarm; overheated loose bus connection identified, ring terminal replaced, connections secured 	4/13; 1 hr 4/27; 1 hr 6/16; at least 6 people x 1 day 7/2-3; 40 hrs 7/10-14; 2 hrs 7/14-23; 6 hrs 8/19; 6 hrs
UPG: <ul style="list-style-type: none"> • shattered glass cover on module identified and repaired 	4/13; out 3 days, 4 hrs repair
Solarex: <ul style="list-style-type: none"> • junction box failure of 2/14 discovered; array shut down (1 of 14 circuits lost due to explosive failure triggered by corrosion and water intrusion) • another corroded source circuit removed and array restored to service at 12/14ths power • junction box retrofit work • additional junction box retrofits, array at 1/2 power • troubleshoot (including I-V curves) and repair loose connection • junction box retrofit—new switches installed 	3/11; out 12 days 3/23; 2 people x 1 hr 7/7; 8 hrs 7/20; 8 hrs 7/29; 4 hrs 10/19; 2 people x 2 hrs

Table C-2
1992 PVUSA Davis Failure-Related Activities
(Cont'd)

Event	Date; Duration
ENTECH: • controller failures: 1/7, 1/8, 1/24, 1/29, 3/9	various dates; 1 hr each occurrence
• roll motor, battery, control board, and charger replaced	2/25-26; 1 person x 3 hrs
• controller replaced	3/17-19; 2 people x 4-1/2 hrs
• tracker controller board failure, possibly from lightning	6/13; 2 weeks
• tracker controller board replaced	7/2; 2 hrs
• tracking controls re-calibrated	7/4; 2 hrs
• stow motor relay failed upon inspection	8/3; 4 hrs
• high wind stow signal inoperative—manual stow under 50 mph gusts	9/25; 1/2 hr
• control board sent out for wind signal repair, system inoperative	9/30-10/23; 1-hr to replace on 10/23
• wind speed circuit failure; checked connections and functions, intermittently okay	10/23; 1 hr
• wind speed sensor checks	10/28, 11/3; 1/4 hr ea.
• restart tracker controller after manual weekend stow	12/7; 0.3 hr

Table C-3
1992 PVUSA Davis Research Activities

Event	Date; Duration
I-V curves taken at APS US-1 array (3 sections installed)	biweekly; 2 people x 1 hr
PG&E installed power quality equipment to monitor power quality and record line disturbances	3/16; 5 people x 4 hrs
Electric field strength measurements (non-intrusive)	4/16; 3 people x 4 hrs 4/28; 5 people x 6 hrs
SSI EMT array: 10 micro-grid modules temporarily replaced by SSI with M-55s to do factory tests after 3-1/2 years of operation	7/24; 5 people x 3 hrs 8/14; 1 person x 4 hrs

Table C-4
1992 PVUSA Host Systems Failure-Related Activities¹

Event	Date; Duration
Maui Sovonics:	
PCU shutdown errors—54 instances. About half of these coincided with known grid disturbances; the others were indicated as dc overvoltages	Various dates; durations ranging from less than 1 hr to several days
Data logger and pyranometers replaced; filtered pyranometer added	4/7; 3 people x 3 hrs
PCU's dc operating voltage settings adjusted (after which trips nearly ceased)	September; unknown date and duration
Module junction box failures—5 instances; in each case the modules were replaced; 2/15, 5/19 (2 modules), 7/20, 12/9	Various; typically 2 people x 4 hrs
One section of module interconnect wiring was replaced after one end melted and frayed at a poor junction box connection	5/19; 1 person x 2 hrs
One module repaired by cleaning connections at the junction box	12/11; 2 people x 4 hrs
Sovonics began retrofitting failed modules with new junction boxes; five repaired modules received in December	
Austin IPC:²	
Inverter fuse blew due to fire/flashover in DAS boxes caused by unprotected transducers in DAS; inverter and PV system taken off line	8/6-25
Inverter fuse replaced, DAS isolated, and inverter restarted	8/26
During array acceptance testing, short circuit current fire began in dc disconnect boxes in mechanical room; cause of fire attributed to inappropriate use of switches	10/7
Inverter operational. All weather, dc, and DAS signals calibrated except for ac output signals; inaccurate signals attributed to a faulty transducer	10/8
New ac transducers installed	11/9
DAS completed and system in full operation	11/10

¹ There were no prescribed maintenance or research activities reported during 1992 for the Maui and Austin arrays.

² Duration of Austin activities was not reported.

Appendix D

PVUSA HOST SITES

Appendix D includes system and site descriptions for each of the PVUSA host sites completed by December 1992 and a map and participants list for all host sites completed or in progress by year's end. A photograph of the completed Austin system is also included.

SYSTEM AND SITE DESCRIPTIONS

PVUSA participants have the opportunity to install and monitor systems which may be smaller but are similar to those at the PVUSA Davis site. PVUSA supplies a data acquisition system and collects and reports information from the host sites. Descriptions of system technology and physical layout for installations completed by year's end appear below. (Host systems for NYSERDA and VEPCO were under construction during 1992.)

City of Austin, Texas

- This 17.9 kW grid-interactive system is located at the City of Austin Convention Center. It features one row of MSEC bi-module PV panels, a 25-kW ac Omnion PCU, an IPC horizontal single-axis structure and tracker drive system, and a PVUSA-specified DAS. In this grid-interactive configuration, the PV system operates in parallel with the utility service to provide supplemental power for the daytime electrical requirements of the convention center.

The array is configured as one row of PV panels oriented on a horizontal North-South axis. It contains 96 modules with a total PV aperture area of 212.1 m². It is located on the top of the eastern wall of the convention center. The tracker drive controller and array monopole disconnects are located at the south end of the row and the winch is located in the center of the row on the west side of the center pedestals. The PCU, dc disconnect switches, and DAS are located inside the convention center.

Maui Electric, Hawaii

- This array consists of 1200 Sovonics EMT modules which are similar to those in the Sovonics Davis array. The modules are tilted at 22° on a fixed south-facing structure designed by Sovonics. The system uses a DECC PCU.

PARTICIPANTS

Maui Electric

Department of Business, Economic Development & Tourism

Maui Electric Company

Photovoltaics for Utility Scale Applications

Sovonics Solar Systems

Maui Economic Development Board

Energy Conversion Devices

U.S. Department of Energy

NYSERDA

New York State Energy Research and Development Authority

New York State Energy Office

State University of New York at Farmingdale

Long Island Lighting Company

City of Austin, Texas

(This project has no additional participants.)

VEPCO

Virginia Electric Power Co.

Commonwealth of the State of Virginia

Figure D-1
PVUSA Host Site Data
(as of April 1993)

Figure D-2
PVUSA Austin Host System, January 1993

Appendix E

KERMAN SITE, SYSTEM DESCRIPTION AND ELECTRICAL DIAGRAM

This section provides a description of the Kerman site, and a schematic of the system.

KERMAN SITE

The Kerman system is located on 10 acres of flat agricultural land several miles outside of the city of Kerman in California's San Joaquin Valley. The 500-kW PV system occupies five acres. Buildings and a parking area occupy two acres; three acres are unused and unimproved. A single residence is located directly across the road from the site.

The buildings include a 12-foot by 16-foot prefabricated electrical control building and a temporary 40-foot trailer to be used as a visitors' center, office, and conference room. Concrete pads are required for the 15-kV outdoor switchgear enclosure, the meteorological instrumentation platform, and utility metering. The installation includes a 25-gallon-per-minute well with a 30-gallon pressure tank.

SYSTEM DESCRIPTION

The Kerman PV system features 12,240 SSI M55VJ PV modules, two 275-kW Omnion series 3200 PCUs, a Robbins one-axis passive tracker system, and a utility-grade SCADA system. In this grid interactive configuration, the PV system operates in parallel with the utility 12.47-kV service supporting a transformer bank in a nearby substation. It will be remotely operated by PG&E's distribution operators.

The array is configured as nine rows of panels oriented on a horizontal north-south axis with a total module area of 5075 m². The tracker passive actuator mechanisms are located along the lengths of the panel rows and use R134a gas (a non-CFC refrigerant) as the working fluid. The PCUs are located at the center of the array field. The SCADA system master unit is located in the electrical control building at the south end of the array field. Adjacent to each PCU is a SCADA field unit which monitors PCU system performance and relays data back to the control room via fiber optic cable. The SCADA field unit is also the interface between the SCADA master unit and the PCU for remote operation.

Figure E-1 provides a single-line diagram of the Kerman electrical system.

Figure E-1
Kerman Electrical Diagram

Appendix F

PVUSA QUALIFICATION TEST SEQUENCE

Figure F-1 illustrates the PVUSA module qualification test sequence. The sequence is being revised under the purview of the IEEE Standards Coordinating Committee 21.

Figure F-1
PVUSA Qualification Test Sequence

Appendix G

TECHNOLOGY TRANSFER ACTIVITIES

Appendix G includes a list of technology transfer activities, including papers, presentations, and visitors to the site.

MEETINGS

In April, Chuck Whitaker attended an IEC TC 82 meeting in Tokyo.

In June, Chuck Whitaker and Brian Farmer participated in a joint IEEE and IEC U.S. TAG meeting in Washington, D.C.

In November, Chuck Whitaker represented PVUSA/PG&E at IEEE and IEC PV Standards Committee meetings in Phoenix, Arizona.

PAPERS AND PRESENTATIONS

In February, Steve Hester presented a paper on the status of PVUSA at the SOLTECH 92 conference held in Albuquerque, New Mexico. In conjunction with the conference, PVUSA also hosted a Technology Transfer Meeting which focused on lessons learned.

In April, Steve Hester presented a paper titled "PVUSA: Results and Experiences" at the ASME International Solar Energy Conference on Maui, and Tammie Candelario presented a poster titled "Photovoltaics in Pacific Gas & Electric Company" at the American Power Conference in Chicago.

In May, Christina Jennings gave a presentation on the current status of PVUSA at the NREL PV Advanced Research and Development 11th Review Meeting in Denver.

In July, a PVUSA Technology Transfer Plan was submitted to the R&D PV Program Manager for review and approval.

In July, Chuck Whitaker gave a presentation titled "Photovoltaic Module and Array Testing at PG&E" at a Sandia/DOE Crystalline PV Technology Project Review meeting.

In September, Steve Hester and Chuck Whitaker gave presentations at an NREL-sponsored PV Performance and Reliability Workshop. Steve's presentation was titled "PG&E's Experience in PV System Performance and Reliability: Remote and Grid-Connected Applications." Chuck's was titled "PG&E's Perspectives on Module Reliability."

In October, the 1991 PVUSA Progress Report was issued.

SITE TOURS

In 1992, PVUSA hosted 147 tours of the Davis site for a total of 598 visitors representing more than 20 countries.

Appendix H
TERMS AND ABBREVIATIONS

APS	Advanced Photovoltaic Systems, Inc.
Availability	Percentage of daylight hours (sunrise to sunset) during which a system supplies net power to the utility grid.
BOS	Balance of System. All equipment and associated labor not part of the actual PV array, such as the support structure, power conditioning unit, and utility grid interconnection equipment.
Capacity Factor	Ratio of actual monthly ac energy production (kWh) divided by the product of the ac rating (kW) and the number of hours per month.
CdTe	Cadmium telluride.
CEC	California Energy Commission.
DAS	Data Acquisition System.
DECC	Delta Electronic Control Corporation.
DOE	U.S. Department of Energy.
Efficiency	Ratio of monthly energy produced to monthly POA insolation during hours when the PCU is operating.
EMT	Emerging Module Technology.
EPRI	Electric Power Research Institute.
IEC	International Electrotechnical Commission.
IEEE	Institute of Electrical and Electronics Engineers.

IPC	Integrated Power Corporation.
MSEC	Mobil Solar Energy Corporation.
NREL	National Renewable Energy Laboratory (formerly Solar Energy Research Institute).
NYSERDA	New York State Energy Research and Development Authority.
O&M	Operation and Maintenance.
PCU	Power Conditioning Unit. Contains a dc-to-ac inverter, system protection and control, and maximum power tracking circuits.
PG&E	Pacific Gas & Electric.
POA	Plane of Array.
PTC	PVUSA Test Conditions. Defined as 1000 W/m ² POA irradiance for flat plate modules, 850 W/m ² direct normal irradiance for concentrators, 20°C ambient temperature, and 1 m/s wind speed.
SC	PVUSA Steering Committee.
SCADA	Supervisory Control and Data Acquisition.
SNL	Sandia National Laboratories.
SSI	Siemens Solar Industries, Inc.
STC	Standard Test Conditions. Defined as 1000 W/m ² POA irradiance for flat plate modules, 850 W/m ² direct normal irradiance for concentrators, 25° or 28°C cell temperature, and air mass 1.5 spectrum.
T&D	Transmission and Distribution.

TRC PVUSA Technical Review Committee.

UPG Utility Power Group.

US Utility Scale.

VEPCO Virginia Electric Power Company.