A national cooperative research project for directly harnessing the power of the sun to generate commercial quantities of electricity.

QUARTERLY TECHNICAL REPORT

Third Quarter 1996

By
PVUSA Project Staff

Pacific Gas & Electric Company
Research and Development Department
San Ramon, CA 94583

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PHASE II -- PHOTOVOLTAICS FOR UTILITY SCALE APPLICATIONS (PVUSA)

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I. SUMMARY

PVUSA's transition to CEC/SMUD management is progressing. The intellectual property valuation was completed and both the Purchase and Sale Agreement and Power Exchange Agreement were completed and submitted to the CEC for signature prior to filing the application with the CPUC. The CEC agreed to sign the documents prior to filing the application with the addition of "escape" clauses. Despite these accomplishments, the application was not filed by the end of the quarter. CPUC approval of PG&E's proposed transfer of PVUSA assets to the CEC is now expected in the spring of 1997.

In the meantime, PG&E and SMUD submitted complementary proposals to the DOE to support July-December 1996 activities and the CEC was heading up long-term planning efforts with Unisun and national stakeholders. In September, the DOE approved PG&E's proposal. This enables PG&E to maintain minimal site operations through 1996. SMUD's agreement was expected to be executed in October.

A major event concerning the CEC's anticipated long-term role with PVUSA occurred in September with the passage of California's utility restructuring bill AB 1890. In it, the CEC is slated to become the independent administrator for public interest RD&D money raised via a non-bypassable electricity surcharge.

PVUSA is now monitoring 20 systems at nine locations with a combined capacity of 1,800 kW. This is the first quarter that performance data are being reported on the Amonix EMT-3 array. One additional 375-kW system is under construction in Yuma, AZ and is scheduled to start up in December 1996. Combined, these systems generated 0.8 million kWh during July through September, increasing the project cumulative total to 9.2 million kWh since 1989. Locations other than Davis are noted next to the supplier's name in Table I.1.

Table I.1
3rd Quarter 1996 PV System Performance Summary

Emerging Module Technologies	Efficiency %	Capacity Factor %	Performance Index %
Amonix	9.5 dc	25	61
AstroPower	4.8 dc	25	87
ENTECH	9.2 dc	31	84
Solarex	6.8 dc	18	73
Sovonics	2.4 dc	20	89
Sovonics (Maui, HI)	3.3 dc	21	100
SCI	5.6 dc	25	85
SSI	8.5 dc	19	77
UPG	2.8 dc	23	94
Utility Scale Systems			
APS	2.5 ac	12	53
ENTECH (Fort Davis, TX)	9.0 ac	16	66
IPC	7.0 ac	34	88
IPC (Austin, TX)	8.0 ac	18	65
IPC (Farmingdale, NY)	not in operation	0	0
IPC (Maspeeth, NY)	6.5 ac	1	8
SSI	not in operation	0	0
SSI (Kerman, CA)	7.1 ac	19	56
UPG (Fort Davis, TX)	9.0 ac	26	97
UPG (Sacramento, CA)	9.7 ac	35	95
NWP (Aurora, CO)	not yet rated	not yet rated	not yet rated

II. PROJECT MANAGEMENT

1. Schedule Analysis and Transition Activities

As shown on Table II.1, only one PVUSA-affiliated PV system has yet to be completed. As of the end of September, construction on UPG's 375-kW (nominal ac power under PTC) system was on schedule. PVUSA is presently discussing DAS design and installation issues and acceptance testing with UPG.

Table II.1
System Installation Schedule

Systems to be installed:	Original Estimated Completion Date	Current Forecast Completion Date
UPG: DOD Yuma, AZ	October 1995	December 1996

The schedule for PVUSA's other major management activity, the transition to CEC/SMUD management, is shaping up as well. CPUC approval of PG&E's proposed transfer of PVUSA assets to the CEC is now expected by spring 1997. As of the end of the quarter, PG&E and the CEC were close to finalizing the application, which has an anticipated processing time of 3 to 4 months. A key component of the application concerning intellectual property was completed in late September by Coopers & Lybrand. (This stems, in short, from concern by the CPUC Office of Ratepayer Advocates in keeping the ratepayers "whole.") Intellectual property was estimated to be about \$360,000 or about 1% of the value of PG&E's transferable assets. Two other contracts that the CPUC will expect to see as part of the application were completed: PG&E submitted the Power Exchange and Purchase & Sale agreements to the CEC for signature on September 18 and September 26, respectively. The application itself is expected to follow shortly.

At the TRC/SC meeting on July 30, PG&E and SMUD presented a plan which would bring SMUD on board with the project by applying for the remaining DOE 1996 funds earmarked for PVUSA. SMUD will then use these funds to support additional research while PG&E maintains minimal site operations through 1996. One of the several task items identified for SMUD is the development and implementation of a small systems test center. Such a center will address one of the primary needs identified earlier by Unisun. The TRC/SC heartily endorsed this approach which will keep the project more active and allow crossover training for SMUD. Consequently, PG&E and SMUD submitted complementary proposals to the DOE to support project activities (PG&E's for Jul-Dec 1996 and SMUD's for Oct 1996-Mar 1997). In September the DOE approved PG&E's proposal and issued an amendment and SMUD's Cooperative Agreement was expected to be in place in October. In anticipation of the DOE funding agreement, SMUD assigned technician Ken Miller a position with full-time duties at SMUD, switching to half-time at PVUSA once the DOE funding agreement is in place. SMUD also posted for a PVUSA site manager in September. The CEC continues to head up long-term planning efforts with Unisun and national stakeholders.

A major event which may affect the CEC's anticipated long-term role with PVUSA occurred in September with the passage of California's utility restructuring bill AB 1890. In it, the CEC is slated to become the independent administrator for public interest RD&D money raised via a non-bypassable electricity surcharge. The CEC had already agreed to assume ownership of PVUSA earlier this year, but was uncertain whether they would be able to continue ownership beyond 1997.

2. Cost Analysis and Funding Activities

In July, PG&E submitted a proposal to the DOE to add \$365,000 to PVUSA's Cooperative Agreement to cover operating expenses through the end of 1996. An amendment was issued by the DOE in September. SMUD applied for \$302,000 but the parties were not able to put a Cooperative Agreement in place for supplemental PVUSA activities by the end of the quarter. (The Cooperative Agreement was issued in mid-October.)

Several meetings took place between PG&E and the Defense Contractor Audit Agency (DCAA) regarding the PVUSA audit for 1987-1994. The DCAA and PG&E resolved outstanding issues regarding A&G rates and other matters. In mid-September, the DCAA notified PG&E that the audit was complete with all items resolved except for one minor item which was referred to DOE. Also this quarter, PG&E prepared and submitted for review the incurred cost claim for 1995.

3. Technology Transfer Activities

Publications, Conferences, and Meetings

On September 4-6, Chuck Whitaker and Tim Townsend attended NREL's PV System Performance and Reliability Workshop in Lakewood, Colorado. Chuck's presentation was titled "Reliability Issues in PV Systems and Components," and Tim's was titled "An Evaluation of Long-Term Degradation at PVUSA." Chuck also attended a UPVG Engineering and Specifications Work Group meeting on September 5 to review technical specifications for the next round of *TEAM-UP*.

Standards work: In September, Brian Farmer and Chuck Whitaker completed their review of the IEEE PAR 1374 concerning terrestrial PV system safety. PVUSA will recommend a yes vote, with comments.

A joint SC/TRC meeting was held at the Davis site on July 30. The principal topics included a project activities update, system performance reviews, presentations on possible new system purchases, and discussions on PVUSA technical services, project transition, and long-term planning.

Safety

Tim Townsend (August) and Paul Hutchinson (September) completed the Red Cross' 8-hour Adult CPR and First Aid training course.

In August, a site safety refresher meeting was held. As follow on activities, the site's MSDS file was updated, and hazard communication materials were distributed.

Site Tours

During the third quarter of 1996, PVUSA hosted 18 tours of the Davis site for a total of 63 visitors.

III. TECHNICAL ANALYSIS - DAVIS SITE

1. System Performance

Throughout the report, standard text that is repeated each quarter will be indented:

Performance data are listed in Table III.1 for eleven Davis systems, including eight EMT arrays and three US systems. DC efficiencies are listed for the EMT arrays and ac efficiencies are listed for the US systems. The insolation totals differ in this table, even for arrays of the same orientation. They differ primarily because this quantity is integrated only when the PCU is on, and the hours of PCU operation vary between arrays. In addition to the instrument uncertainty (typically $\pm 3\%$), there are also small differences in the field of view from each array.

Figure III.1 tracks the recent monthly energy supplied by the eight Davis site EMT systems. Figure III.2 shows the same information for the three US systems. The right scales refer to insolation measured at the site weather station (integrated over all hours). The 30° tilt insolation is shown on both plots as a reference trend for the fixed tilt systems, and on Figure III.2, the horizontal N-S 1-axis insolation is shown as a reference trend for the IPC and SSI tracking systems. Smoothed trend lines showing the average insolation for both orientations are also included, along with monthly error bars indicating $\pm$ one standard deviation about each trend line. The average insolation dates from 1989 for the fixed tilt orientation and from 1991 for the tracking orientation.

Prevailing quarterly conditions

There were three grid outages this quarter. One on July 19 caused a 6-second outage, one on August 10 caused a 3-hour outage, and one on September 16 resulted in a 30-minute outage. The August and September outages caused fuse and MOV failures on the APS system, but no other equipment was damaged. There were no significant weather-driven irregularities in generation this quarter, although the lack of rain permitted heavy deposits of dust and bird droppings to accumulate. Only the Amonix array, which was washed once per week by an Amonix technician, remained clean. Generation from the other systems was reduced by about 10% due to soiling.

The insolation each month was consistent with the monthly averages dating from 1989. In July and August, the air temperature was moderately warmer than normal and the wind speeds were moderately less than normal, but the deviations were probably too small to have a significant effect on generation. September temperatures and wind speeds were very close to normal.

Special quarterly topics

Appendix A summarizes results of work done this quarter to evaluate long-term degradation for 10 PVUSA systems that have been operating at least three years. Updated ratings were folded into this quarter's performance index calculations. Most of the systems' degradation trends should not be considered significant at this stage, as the measurement uncertainty is generally larger than the degradation rates and the operating periods have not been lengthy enough to establish good correlations.

Performance, by system

SSI: Data from April of this year showed less than a 2% drop in rated power over the past 2.5 years, compared to a 10% drop over the first 4.8 years of operation. The overall drop from 18.7 kWdc in 1989 to 16.5 kWdc now corresponds to an exponential degradation rate of

1.7%/yr. For the quarter, output was 23% lower than expected. A close look at Figure III.1 shows the output was low in July and August compared to the expected trend from the other fixed tilt arrays. Not counting three grid disturbances that shut down the entire site, there were 17 PCU shutdowns between July 1 and August 9 that resulted in 5 minutes to over a day of downtime with each occurrence. Frequency errors were indicated by the PCU in almost every case. The frequency errors ceased after the frequency range potentiometer was adjusted on August 9, although there were two more PCU trips due to synchronization errors after the adjustment.

Solarex: Data from April of this year showed a 3.6% drop in rated power over the past 2.5 years, compared to a 9% drop over the first 3 years of operation. The overall drop from 15.7 kWdc in 1990 to 13.7 kWdc now corresponds to an exponential degradation rate of 2.4%/yr. The quarterly generation was 27% lower than expected. Four of eight PCU error shutdowns occurred in September, but there were no array problems.

Sovonics: Data from April of this year showed a 6% drop in rated power over the past 2.5 years, compared to a 16% drop over the first 4.3 years of operation. The overall drop from 17.3 kWdc in 1989 to 13.7 kWdc now corresponds to an exponential degradation rate of 3.4%/yr. The generation this quarter was only 11% lower than expected, which is surprisingly high, considering the results for the other systems that also went unwashed. In addition, there were 10 PCU shutdowns, and a month-long period in July when the output was reduced by 15% because of a failed panel.

UPG: Data from April of this year showed a 4% drop in rated power over the past 2.5 years, compared to a 12% drop over the first 3.8 years of operation. The overall drop from 15.7 kWdc in 1989 to 13.2 kWdc now corresponds to an exponential degradation rate of 2.7%/yr. Generation was only 6% lower than expected, but this figure is an estimate. The ac power transducer began blowing fuses repeatedly early this quarter, and the problem remains unresolved. In the meantime, the ac energy is estimated to be 90% of the dc energy.

ENTECH: Data from April of this year showed a 6% drop in rated power over the past 2.5 years, compared to a 3% *increase* over the first 2.5 years of operation. The overall drop from 16.5 kWdc in 1991 to 15.9 kWdc now corresponds to an exponential degradation rate of 0.7%/yr. The system operated reliably this quarter, with a performance index of 84%. There were only two instances of PCU trips and one occasion when the tracker was observed to be slightly off target. In September, at 3M's request, each of the module lenses was inspected closely for signs of aging. Three cracked lenses were identified, several others appeared to have small lamination defects, and there was widespread evidence of surface defects, or crazing. A short report of these findings is being prepared for distribution to ENTECH, 3M, and interested PVUSA members.

AstroPower: There were no problems with the array and no (local) PCU trips, but its performance index was only 87%. Soiling and grid outages are believed to be responsible for the reduced output.

SCI: There was one occasion in July and another in September when local PCU trips resulted in a total of two days of down time. Both PCU trips were accompanied by a failed power transducer fuse and burnt capacitor terminal. The quarterly performance index was 85%. In

July, NREL noted that SCI modules at their test site appeared to bow outwards under high temperatures. PVUSA's modules also appear to flex slightly, but no modules have cracked.

Amonix: The first quarter of official data collection at Amonix began July 1, even though work is ongoing to resolve sub-par efficiency, unreliable tracking, and cell corrosion. PVUSA is using an interim rating of 16.0 ± 0.6 kWdc that was calculated using Dec '95-Jan '96 data (the target was 19.0 kWdc) until Amonix indicates substantial improvements have been implemented.

The quarterly performance index was only 61%, even though the array was washed weekly by an Amonix technician. The PCU suffered local trips on five occasions, but the tracking system had seven recorded incidents of tracking failure, and there were five other occasions when the array was stowed manually at night/weekends and restarted manually in the morning because of unreliable tracker control. Amonix made one diagnostic visit in September and PVUSA consulted with tracker controller manufacturer ATS by telephone on several occasions.

One topic investigated this quarter was the extent to which tracking system vibrations contribute to ac power ripple. The conclusion: very little. It was hypothesized that even at low wind speeds, under-damped vibrations from the tracker gearing after each ~8-10 sec. update might be causing significant aiming errors. The current and power ripple were measured to be about $\pm 2\%$ rms under mild conditions. The power did drop sharply by 10% when the array was manually shaken to simulate a 20 mile per hour wind. However, the same $\pm 2\%$ ripple was observed on the neighboring ENTECH system. For both systems, the PCU's maximum power tracker was judged to contribute most of the ripple, because when observed under fixed voltage operation, ripple was greatly reduced for both systems.

APS: This quarter's performance index was just 53%, even with a newly updated and lower rating of 378 kW used in the P.I. calculation. Data from April of this year showed a 12% drop in rated power over the past 2.5 years, compared to an 11% drop the first year of operation. The overall drop from 479 kWac in 1992 to 378 kWac now corresponds to an exponential degradation rate of over 6%/yr (5%/yr after the first year).

The system ran at one-fourth power for nearly a month after a major grid outage on August 10 caused several fuses and MOVs to fail. The system was restored to half power on September 5 and to full power on September 13 after replacement fuses arrived. Unfortunately, another grid outage on September 16 caused fuses in one inverter to clear again, and the system was not restored to full power until September 20.

IPC: This quarter's P.I. was 88%. The system rating was updated this quarter using data from May 1996 (after Kenetech installed an upgraded control unit board and modified the peak power tracking algorithm). The updated rating is 191 kWac, which corresponds to an exponential degradation rate of less than 1%/yr. after nearly 3 years of operation.

There was only one minor operational problem; the tracker became stuck at its limit switch once power was restored after a September 16 grid outage and needed to be reset manually. Kenetech also made one brief visit in August to swap in a new PROM chip and fix a faulty ac power signal. In September, PG&E technicians performed ac and dc signal calibrations.

SSI: The system remained shut down after problems developed in June that resulted in a grass fire beneath five failed modules and a failed bypass diode. The problems may have begun with the PCU, which was studied extensively this quarter and found to have faulty waveform fingerprints. Corrosion and burned components were also observed. The unit was started briefly late in September to test its operation without the fire-damaged source circuit, but afterwards wouldn't wake up properly. The system was shut down while a troubleshooting and repair plan and incident report were being prepared in October. An unrelated activity concerned a failed passive tracker actuator. The unit was removed in July and oil-soaked dirt below the tracker was moved to a PG&E hazardous waste disposal facility in August.

Table III.1 PVUSA Davis Systems: Performance Summary

Characteristics	SSI	Sov-onics	UPG	Solarex	EN-TECH	Astro-Power	SCI	Amonix	APS	IPC	SSI
Orientation(fixed flat plate, tracking)	30° ffp	30° ffp	30° ffp	30° ffp	2-ax trk.	30° ffp	30° ffp	2-ax trk.	30° ffp	1-ax trk.	1-ax trk.
Initial rating, kW	18.7 dc	17.3 dc	15.7 dc	15.7 dc	16.5 dc	17.1 dc	12.0 dc	16.0 dc	479 ac	196 ac	67 ac
Installation date	1/89	6/89	12/89	10/90	3/91	11/94	9/95	10/95	9/92	6/93	5/94
Module area, m ²	169	497	477	182	172	292	190	159	11,520	2,443	845
System	Quantity		1995	Jan-Sep 1996	Jan-Mar 1996	Apr-Jun 1996	Jul-Sep 1996				
SSI	AC kWh		27,119	21,920	5,231	8,981	7,708				
	Performance Index %		92	85	88	96	77				
	DC eff. %		9.7	9.3	9.9	9.6	8.5				
	AC cap.fac. %		17.2	18.5	13.3	22.8	19.4				
	Insol. kWh/m ²		1,961	1,580	361	605	614				
Sovonics	AC kWh		22,489	19,560	4,417	8,011	7,132				
	Performance Index %		91	94	90	100	89				
	DC eff. %		2.5	2.4	2.1	2.6	2.4				
	AC cap.fac. %		16.2	18.7	12.7	23.1	20.3				
	Insol. kWh/m ²		1,961	1,528	364	607	557				
UPG	AC kWh		22,464	20,757	4,904	8,181	7,672				
	Performance Index %		91	100	100	100	94				
	DC eff. %		2.9	2.9	2.9	2.9	2.8				
	AC cap.fac. %		17.0	20.9	14.9	24.8	23.0				
	Insol. kWh/m ²		1,956	1,609	354	619	636				
Solarex	AC kWh		21,002	17,975	4,305	7,609	6,061				
	Performance Index %		83	84	84	94	73				
	DC eff. %		7.1	7.3	7.7	7.6	6.8				
	AC cap.fac. %		15.9	18.1	13.1	23.1	18.2				
	Insol. kWh/m ²		1,958	1,537	363	620	554				
ENTECH	AC kWh		25,745	25,391	5,019	9,817	10,555				
	Performance Index %		75	87	87	90*	84				
	DC eff. %		10.1	10.0	10.0	10.7	9.2				
	AC cap.fac. %		18.8	24.8	14.7*	28.8	30.6				
	Insol. kWh/m ²		1,956	1,350	287	464	599				
AstroPower	AC kWh		28,785	24,465	5,917	9,627	8,921				
	Performance Index %		94	94	97	100	87				
	DC eff. %		5.5	5.2	5.6	5.4	4.8				
	AC cap.fac. %		20.4	23.1	16.8	27.4	25.1				
	Insol. kWh/m ²		1,969	1,608	367	611	630				
Solar Cells, Inc.	AC kWh		4,519	16,589	3,977	6,502	6,110				
	Performance Index %		n/r	93	100	98	85				
	DC eff. %		6.5	6.0	6.5	6.1	5.6				
	AC cap.fac. %		14.1	22.5	16.3*	26.6	25.6				
	Insol. kWh/m ²		378	1,623	372	614	637				
Amonix	AC kWh		5,341	15,855	1,305	6,144	8,406				
	Performance Index %		n/r	61	n/r	n/r	61				
	DC eff. %		n/r	9.5	n/r	n/r	9.5				
	AC cap.fac. %		n/r	25.4	n/r	n/r	25.4				
	Insol. kWh/m ²		333	1,113	116	381	616				
APS	AC kWh		535,129	422,738	100,516	192,949	129,273				
	Performance Index %		73	67	68	80	53				
	AC eff. %		2.8	3.1	3.4	3.3	2.5				
	AC cap.fac. %		12.8	13.4	9.6	18.4	12.2				
	Insol. kWh/m ²		1,838	1,291	312	517	462				
IPC	AC kWh		187,335	351,696	58,634	147,091	145,971				
	Performance Index %		40	87	76	90	88				
	AC eff. %		7.2	7.5	7.9	7.8	7.0				
	AC cap.fac. %		10.9	27.3	13.7	34.4	33.7				
	Insol. kWh/m ²		1,774	2,017	346	811	860				
SSI	AC kWh		90,514	30,810	17,663	13,098	49				
	Performance Index %		57	21	67	23	0				
	AC eff. %		6.9	7.8	8.4	7.0	0				
	AC cap.fac. %		15.4	7.0	12.1	9.0	0				
	Insol. kWh/m ²		2,036	492	265	222	5				

* The three values marked with an asterisk differ slightly from when they were first reported.

Figure III.1

Figure III.2

Efficiency

Figures III.3 and III.4 show monthly average efficiencies for the EMT arrays and US systems, respectively. DC efficiencies are reported for the eight EMT arrays, and ac efficiencies are reported for the three US systems. Except for the ENTECH array, the efficiencies are calculated as the ratio of monthly energy produced to monthly plane-of-array insolation during hours when the PCU was operating. The ENTECH array, which uses a 22X concentrating lens and two-axis tracking structure, shades portions of itself and its pyrheliometer during the early and late hours of the day. Therefore, its efficiency calculations are based on the hours between 9 a.m. and 3 p.m. PST, when shading does not occur at any time of the year.

For most of the EMT arrays, their efficiencies dropped slowly and steadily throughout the summer as dirt accumulated, even though the average operating temperatures dropped by 4-5 degrees between August and September. The SSI array seemed to be impacted the most, with a relative drop in efficiency of 16% between July and September. The Sovonics array's seasonal efficiency pattern is usually the opposite, peaking in the summer. This year would be similar except a June module failure caused a relative drop of 15% throughout July. Compared to its rated dc efficiency of 11.8%, the Amonix array efficiency was relatively low by 20% to 30% each month, even though the array was kept clean. Tracking error and corroded cells are believed to be the principal causes for the sub-par efficiency.

For the three US systems shown on Figure III.4, the efficiency trends have tended to be more erratic, being more influenced by component failures than weather. This was true again this quarter, although the IPC system's trend was consistent with its seasonal norm. APS' dip in August and September was mostly due to running on fewer than four inverters much of the time. SSI was down throughout the quarter.

Figure III.3

Figure III.4

2. Solar/Weather Data

Table III.2 lists several solar radiation, temperature, and wind speed statistics for this quarter, along with data from last year. Figure III.5 shows this year's monthly average air temperature and wind speed trends and compares them to the site averages dating from 1989. Error bars of one standard deviation around the site averages indicate typical year to year variations.

The global horizontal insolation averaged a little over 7 peak hours per day for the quarter, equal to the site's seasonal average dating from 1989 and about 2% above the DOE's published long-term average insolation for Davis. The 24 °C quarterly average air temperature was slightly above the site's 8-yr. seasonal average of 23 ± 1 °C and the DOE average 22 °C. The warmest temperature ever recorded at PVUSA, 46 °C (115 °F), occurred on August 10, the same day that a widespread power outage affected much of the western US. There was no rain this quarter, but the site normally receives only a trace during the summer months anyway. The average wind speed of 2.6 m/s was moderately below the normal seasonal average of 2.8 ± 0.1 m/s ($\pm$ refers to one standard deviation).

Table III.2
Solar/Weather Summary

Insolation, kWh/m ² ; Peak irradiance, W/m ²	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
DOE LT-Avg. global horizontal insol.	1,838	1,585	285	658	642
Global horizontal insolation	1,773	1,586	281	647	658
Peak 10-min. avg. irradiance	1,186	1,183	1,081	1,183	1,066
Global 30° tilt insolation	1,989	1,709	382	635	692
Peak 10-min. avg. irradiance	1,209	1,268	1,268	1,192	1,116
Global normal insolation	2,823	2,473	492	948	1,033
Peak 10-min. avg. irradiance	1,267	1,310	1,310	1,259	1,220
Horizontal 1-axis tracking insolation	2,603	2,301	406	918	977
Peak 10-min. avg. irradiance	1,236	1,181	1,080	1,181	1,140
Direct normal insolation	2,123	1,781	336	625	820
Peak 10-min. avg. irradiance	1,007	1,004	1,004	963	979
Minimum T _{ambient} , °C	-1.3	-1	-1	4	9
DOE LT-Avg. T _{ambient} , °C	15	16	9	18	22
Avg. T _{ambient} , °C	16	18	11	19	24
Maximum T _{ambient} , °C	42	46	28	40	46
Avg. wind speed, m/s	3.1	3.1	3.4	3.3	2.6
Max. wind speed, m/s (sustained 10-min.)	17.8	16.1	13.8	16.1	9.6

Figure III.5

3. Operation and Maintenance

Table III.3 summarizes PVUSA's Davis O&M activities. This summary does not include Data Acquisition System (DAS) O&M activities. Host system activities are described along with host system performance in the next section of the report. The activities are identified as either routine preventive maintenance (including planned outages), or failure-related (including forced outages) activities.

Rounded to whole hours, the total time spent on preventive maintenance activities this quarter by PVUSA (excludes time spent by contractors) was 23 hours. PVUSA time spent on failure-related activities was 198 hours, three-fourths of which was spent diagnosing the fire, module/diode, and PCU failures on the SSI US-1 system that occurred back in June 1996.

Table III.3
July - September 1996 O&M Summary

O&M type (and code)	Event	Date: Force x Time (default is 1 person)
Preventive	<u>Site BOS:</u>	
	Read meters and report to PG&E Power Contracts Department	Monthly; @ 0.5 hr ea.
(DMP-017)	Remove weeds from tour path, roads, entry area	7/11, 8/23, 9/14; @ 1 hr ea.
(DMP-004)	Check water wagon, scissors lift, FourTrax, and sump pump	Monthly; @ 1.0 hr ea.
(DMP-007)	Check field safety boxes, fire extinguishers, and perimeter fence	Quarterly; 1.5 hr
(DMP-001)	<u>US-1 APS:</u> service PCU air filters, test emergency lights	Monthly; @ 0.5 hr ea.
(DMP-005)	adjust PCU operating limits	Quarterly; 0.25 hr
(DMP-002)	<u>US-1 IPC:</u> service PCU air filters, check tracker clock & alignment	Monthly; @ 0.5 hr ea.
(DMP-028)	replace tracker oil	9/27 (bi-annual); 3 hrs
(DMP-011)	<u>US-1 SSI:</u> Check array, change transformer tap, clean tracker covers, lube bearings	9/30 (2nd semi-annual); 1.5 hrs
(DMP-003)	<u>EMT-1 ENTECH:</u> Check array, tracker, clock, wind sensor, batteries	Monthly; @ 0.5 hr ea.
(DMP-006)	check tracker gear motor oil, lube tilt & roll drive bearings	Quarterly; 1 hr
(DMP-035)	<u>EMT-3 Amonix:</u> Check array, tracker, clock, UPS	Monthly; @ 0.5 hr ea.
	Wash array (by Amonix)	Weekly; @ 1 hr ea. (non-PVUSA)
(DMP-015)	<u>EMT-1 Sovonics:</u> Inspect array, seasonal PCU voltage adjustment	9/27 (2nd semi-annual); 0.5 hr
(DMP-013)	<u>EMT-1 SSI:</u> Inspect array, seasonal PCU voltage adjustment	9/27 (2nd semi-annual); 0.5 hr
(DMP-014)	<u>EMT-1 Solarex:</u> Inspect array, seasonal PCU voltage adjustment	9/27 (2nd semi-annual); 0.5 hr
(DMP-016)	<u>EMT-1 UPG:</u> Inspect array, seasonal PCU voltage adjustment	9/27 (2nd semi-annual); 0.5 hr

Table III.3 cont'd.
July - September 1996 O&M Summary

O&M type	Event	Date: Force x Time (default is 1 person)
Failure-related	Site BOS: (10 hours)	
	Restore power and notify authorities after three grid outages	7/19, 8/10, 9/16; @2 x 1 hr
	Repair scissors lift	7/26; 4 hrs
	EMT-1 Sovonics: (5 hours) Disconnect source circuit due to voltage imbalance	7/11; 2 x 0.5 hr
	Reset PCU after shutdowns from synch. errors, dc overvoltage, and excessive reverse power	10 occasions; @ 0.1 hrs ea.
	Replace burnt module	7/31; 3 hrs
	EMT-1 SSI: (2.3 hours) Reset PCU after shutdowns from synch. or frequency errors	19 occasions; @ 0.1 hrs ea.
	Adjust PCU frequency trip upper limit	8/9; 2 x 0.2 hrs
	EMT-1 Solarex: (0.8 hours) Reset PCU after shutdowns from synch. error or excessive reverse power	8 occasions; @ 0.1 hr ea.
	EMT-1 UPG: (1.3 hours) Reset PCU after synch. error shutdowns	3 occasions; @ 0.1 hr ea.
	Replace ac power transducer fuse (twice)	7/11, 7/23; @ 0.5 hr ea.
	EMT-1 ENTECH: (0.7 hours) Reset PCU after synch. error shutdowns	2 occasions; @ 0.1 hr ea.
	Tracker off target; realigned	9/9; 0.5 hr
	EMT-3 Amonix: (5.6 hours) Reset PCU after various error shutdowns	5 occasions; @ 0.1 hr ea.
	Replace PCU ac power transducer fuse	7/11; @0.1 hr
	Reset stalled tracker	7 occasions; @ 0.25 hr ea.
	Manually stow tracker for safety	5 occasions; @ 0.25 hr ea.
	Assist Amonix with diagnostics/troubleshooting	9/11; 2 hrs.
	EMT-3 SCI: (1.2 hours) Reset PCU after synch. error shutdowns	2 occasions; @ 0.1 hr ea.
	Repair burnt PCU capacitor connector and replace fuse (twice)	7/29, 9/11; @ 0.5 hr ea.
	US-1 IPC: (1.25 hours) Reset tracker after outage	9/16; 0.25 hr
	Repair ac power signal and replace EPROM	8/28; 1 hr
	US-1 APS: (14.6 hours) Attempt resets after grid disturbances or unspecified reasons	4 occasions; @ 0.25 hr ea.
	Replace MOVs (total 8) and 400 A ac fuses (10 @ \$50)	3 occasions; total 13.5 hrs
	Replace dead security lamp battery	8/26; 0.1 hr
	US-1 SSI: (155 hours) Investigate array fire (test diodes, PCU, source circuits, replace 5 burnt modules)	several days; total 150 hrs for 6 people
	Remove failed tracker actuator, take contaminated soil to PG&E facility	7/3, 8/1; 5 hrs total

IV. OTHER PVUSA SITES

1. Summary

Figure IV.1.a shows the location and lists basic information about PVUSA's various sites. In addition to the Davis and Kerman sites within PG&E's service territory, host systems are operating in Kihei, HI, Austin, TX, Farmingdale, NY, Maspeth, NY, Sacramento, CA, Fort Davis, TX, and Aurora, CO. There are presently 20 systems totaling 1.8 MW in the PVUSA network. One more host system is under construction, a 375-kW system at a US Department of Defense site in Yuma, AZ.

At a glance, Figure IV.1.b compares how much insolation the various sites have been receiving—and how well their systems have been using it. Two key statistics are presented: this year's cumulative global horizontal insolation, expressed as an average daily quantity; and this year's cumulative performance index. Note the summary table at the beginning of the report lists current quarter performance, not cumulative annual.

The following subsections include detailed performance information for operating sites.

Most of the sites which have had data available throughout this year have averaged between 5½ and 6 peak hours per day of global horizontal insolation (GHI). Two sites, Austin and Maspeth, have averaged somewhat less—about 5 and 4 hours per day, respectively.

Farmingdale, NY data have not been available this year, but that site's insolation is usually very similar to the nearby Maspeth site. Data for the Aurora, CO site were collected throughout this quarter but are not yet included on Figure IV.1.b, as sub-par PCU, source circuit, and tracker operations have caused a delay in rating the system.

Over this quarter alone, the Aurora site averaged 6 peak hours per day of GHI, equal to its long-term average and about the same as the quarterly GHI received at the Austin and Maui sites. The Davis, Kerman, and Sacramento sites each averaged approximately 7 peak hours of GHI this quarter. The quarterly GHI was about 20% lower than normal at both the Fort Davis and Maspeth sites, with Fort Davis receiving just 5½ peak hours per day and Maspeth 4 hours per day.

Through this year's first three quarters, seven of PVUSA's 17 systems with data available have operated very well, generating at least 90% of their expected energy. Another four systems have generated at least 80% of their expected amounts. The performance of the remaining six systems has ranged from fair (67% for APS) to very poor (7% for IPC-Maspeth and 21% for SSI US1-Davis). While PCU problems continue to be the principal cause of down time for these six systems, module, source circuit wiring, and tracker failures have also been responsible for significant amounts of lost generation.

PVUSA SITE DATA

Status through 9/96: 20 Systems Totaling 1,800 kW

Figure IV.1.a

Figure IV.1.b

2. Kerman

As part of an effort to evaluate long-term system degradation, an updated rating of 476 kW was calculated this quarter using data from April 1996. Compared to the original rating of 498 kW, this corresponds to a degradation rate of 1.6%/yr. However, with a rating procedure uncertainty of as much as $\pm 5\%$, this result is not statistically significant after just 2.8 years of operation. (The rating histories of Kerman and ten other PVUSA systems are summarized in Appendix A.) The plant's original rating will continue to be used for descriptive purposes and for calculating capacity factors, but the performance index from this quarter on will account for the expected reduced output via the degradation adjustment factor ($476/498 = 0.96$).

Tables IV.2.a and IV.2.b summarize the system's past and current year PV system performance, solar insolation, and weather data. The quarterly generation was just 56% of expected, as there were several interruptions that affected either or both of the PV and DAS systems. There was only one two-week stretch at the end of September in which both of the system's PCUs stayed on line reliably. Data were either missing or corrupted on 34 (of 92) days, requiring some quantities to be estimated and others to be filled in using data from nearby weather stations.

PCU #2 would not operate in July, despite efforts by PG&E's Fresno staff to reset it on several occasions and to replace a control board on one occasion. There was also a two-day outage in mid-July after which PCU #1 restarted, but then ran with a 30 volt imbalance. In early August, PVUSA and Fresno staff corrected the imbalance on array field #1 by replacing two blown dc source circuit fuses. They also restored array field #2 to full power by replacing MOVs and reconnecting two source circuits that had been manually switched out earlier this year after their MOVs failed. Lastly, they got both PCUs to operate by cleaning and resetting connections on the units' PLC control boards. Within a few days PCU #1 began to trip repeatedly and the site's SCADA system stopped communicating. After several days, PG&E's Fresno staff reloaded the SCADA software, but some signals remained frozen until a new SCADA board was installed in mid-September. Although both PCUs ran for the last two weeks of the quarter, PCU #1 tripped again at the beginning of October and would not respond to Fresno's remote reset attempts.

Table IV.2.a
Kerman Performance Summary

SSI system characteristics	
Rating:	498 kW ac
Installation date:	6/93
Total module area:	5210 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
Performance Index %	51	55	45	57	56
AC kWh	586,570	523,919	78,515	233,688	211,716
AC eff. %	8.1	7.7	7.4	8.3	7.1
Cap. fac. %	13.4	16.0	7.2	21.5	19.2
Max. ac kW	498	432	364	432	373
Wtd. avg. T _{module} °C	40	43	34	41	48
POA insol. (PCU on) kWh/m ²	1,279	1290	192	526	572

Table IV.2.b
Kerman Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
1-axis insol. kWh/m ²	est. 2,513	est. 2,155	est. 374	est. 893	est. 888
Horiz. insol. kWh/m ²	1,781	1,554	284	659	611
LT-Avg. horiz. insol. kWh/m ²	1,899	1,619	307	664	648
Peak 1-axis irradi. W/m ²	1,238	1,134	1,004	1,109	1,134
Peak horiz. insol. W/m ²	1,158	1,124	1,098	1,124	1,076
Min. T _{amb} °C	2	0	0	3	n/a
Avg. T _{amb} °C	19	19	14	21	23
LT-Avg. T _{amb} °C	17	19	12	21	26
Max. T _{amb} °C	43	43	29	42	43
Avg. wind speed m/s	2.6	2.7	2.4	3.4	2.4
Max. wind speed m/s	12.7	10.9	10.9	10.5	7.8

3. Maui

Table IV.3.a summarizes past and current year performance for the Maui Sovonics array. Table IV.3.b summarizes solar/weather data. With the exception of a module j-box failure on September 28 that reduced system output by about 15% over the last three days of the quarter (reducing quarterly generation by less than 0.5%), the system operated very reliably. The calculated quarterly performance index was still slightly above—but for reporting purposes, capped at—100%. (By definition, the index cannot exceed 100%. Measurement errors can cause the index to sometimes exceed 100%.)

Maui Electric reported that other than weekly inspections and yard maintenance, the only other maintenance activity this quarter concerned removing NREL's infrared PSP and shipping it back to them. The module j-box failure noted above was repaired by Maui Electric in October. With one failure this quarter, the total number of modules or module connections that have failed throughout seven years of operation now stands at 57 out of 1200 modules. The number of failed modules by year from 1990 through 1996 is 13, 11, 5, 6, 9, 7, and 6.

Table IV.3.a
Maui Performance Summary

Sovonics array characteristics	
Rating:	18.5 kW dc, 17.6 kW ac
Installation date:	10/89
Total module area:	497 m ²
Orientation:	22° tilt, south facing

Quantity	1995	cumul. 1996 (based on 245 days due to lost data)	Jan-Mar '96 (based on 62 days due to lost data)	Apr-Jun '96	Jul-Sep '96
Performance Index %	97	100	100	97	100
AC kWh	31,006	21,259	5,605	7,454	8,200
DC eff. %	3.3	3.3	3.3	3.2	3.3
Cap. fac. %	20.1	20.5	21.4	19.4	21.1
Max. ac kW	18.9	18.8	18.8	16.5	17.3
Wtd. avg. T _{module} °C	44	45	42	45	47
POA insol.(PCU on) kWh/m ²	2,037	1,405	361	514	530

Table IV.3.b
Maui Solar/Weather Summary

Quantity	1995	cumul. 1996 (based on 245 days due to lost data)	Jan-Mar '96 (based on 62 days due to lost data)	Apr-Jun '96	Jul-Sep '96
POA insol. kWh/m ²	2,139	1,430	376	519	535
Horiz. insol. kWh/m ²	2,057	1,456	316	572	568
LT-Avg. horiz. insol. kWh/m ²	2,009	1,768	600	576	592
Peak POA irradi. W/m ²	1,218	1,240	1,221	1,240	1,153
Peak horiz. irradi. W/m ²	1,291	1,209	1,184	1,209	1,163
Min. T _{amb} °C	15	14	14	18	21
Avg. T _{amb} °C	28	28	25	29	30
LT-Avg. T _{amb} °C	24	24	23	24	26
Max. T _{amb} °C	42	45	45	42	43
Avg. wind speed m/s	3.6	3.6	4.1	3.4	3.4
Max. wind speed m/s	12.4	13.8	13.8	11.0	11.4

4. Austin

An updated rating of 16.1 kW was calculated this quarter using data from April 1996, about 10% below the system's original rating of 17.9 kW calculated using April 1993 data. This corresponds to an exponential degradation rate of 3.5%/yr, but the result may only be marginally significant. The study period is still fairly short, and other correctable factors such as instrument calibrations, soiling, partial failures, or non-ideal PCU maximum power tracking have not been ruled out. The plant's original rating will continue to be used for descriptive purposes and for calculating capacity factors, but the performance index from this quarter on will account for the expected reduced output via the degradation adjustment factor ($16.1/17.9 = 0.90$).

Table IV.4.a summarizes past and current year performance for the Austin IPC system. Table IV.4.b summarizes solar/weather data. The Austin site's performance index remained poor again this quarter. This was partly due to recurring nuisance trips of its PCU, particularly in July and September. In terms of lost energy, an equally significant problem developed with the tracking system after a severe storm on August 19. Austin's Leslie Libby checked the tracker and concluded one or more of its components may have been damaged by a transient. The tracker's positioning has become inaccurate and erratic and its programmable controller won't respond to manual attempts to correct corrupted setpoint values. IPC will be consulted for additional troubleshooting.

Table IV.4.a
Austin Performance Summary

IPC system characteristics	
PTC Rating:	17.9 kW ac
Installation date:	7/92
Total module area:	212 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
Performance Index %	77	58	43 ¹	60	65
AC kWh	25,732	16,077	2,973	6,106	6,998
AC eff. %	7.6	7.9	7.9	7.7	8.0
Cap. fac. %	16.4	13.7	7.6	15.6	17.7
Max. ac kW	17.6	18.4	16.8	18.4	17.7
Wtd. avg. T _{module} °C	43	45	33	46	50
POA insol. (PCU on) kWh/m ²	1,614	969	180	375	414

Table IV.4.b
Austin Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
POA insol. kWh/m ²	1,855	1,774	391	625	758
Horiz. insol. kWh/m ²	1,599	1,375	304	493	578
LTAvg. horiz. insol. kWh/m ²	1,700	1,454	349	543	562
Peak POA irradi. W/m ²	1,096	1,141	1,102	1,141	1,086
Peak horiz. irradi. W/m ²	1,129	1,401	1,006	1,177	1,401
Min. T _{amb} °C	-8	-6	-6	6	13
Avg. T _{amb} °C	23	25	15	29	31
LTAvg. T _{amb} °C	20	22	12	24	28
Max. T _{amb} °C	45	44	42	44	43
Avg. wind speed m/s	1.7	2.2	2.2	2.6	1.8
Max. wind speed m/s	10.6	8.8	8.8	6.8	7.8

¹ This value was incorrectly shown as 45% in the 1st quarter report.

5. NYSERDA

Table IV.5.a summarizes the system's past and current year performance. Table IV.5.b summarizes solar/weather data. The system has been off line since September 1995 due to a variety of grid, PCU, wiring, tracker, and DAS problems. This summer, NYSERDA solicited bids from two potential firms to revamp the PVUSA host site system at Farmingdale along with other NYSERDA systems nearby. As of late September, NYSERDA was preparing to award a contract but did not have a repair schedule available.

Table IV.5.a
NYSERDA Performance Summary

IPC system characteristics	
Temporary rating:	17.9 kW ac
Installation date:	8/93
Total module area:	212 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
Performance Index %	38	n/a	n/a	n/a	n/a
AC kWh	11,084	n/a	n/a	n/a	n/a
AC eff. %	7.8	n/a	n/a	n/a	n/a
Cap. fac. %	7.1	n/a	n/a	n/a	n/a
Max. ac kW	20.9	n/a	n/a	n/a	n/a
Wtd. avg. T _{module} °C	38	n/a	n/a	n/a	n/a
POA insol. (PCU on) kWh/m ²	674	n/a	n/a	n/a	n/a

Table IV.5.b
NYSERDA Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
POA insol. kWh/m ²	est. 1,723	n/a	n/a	n/a	n/a
Horiz. insol. kWh/m ²	est. 1,340	n/a	n/a	n/a	n/a
LT-Avg. horiz. insol. kWh/m ²	1,460	1,244	255	507	482
Peak POA irradi. W/m ²	1,080	n/a	n/a	n/a	n/a
Peak horiz. irradi. W/m ²	1,267	n/a	n/a	n/a	n/a
Min. T _{amb} °C	n/a	n/a	n/a	n/a	n/a
Avg. T _{amb} °C	n/a	n/a	n/a	n/a	n/a
LT-Avg. T _{amb} °C	13	14	2	17	23
Max. T _{amb} °C	n/a	n/a	n/a	n/a	n/a
Avg. wind speed m/s	1.7	n/a	n/a	n/a	n/a
Max. wind speed m/s	10.4	n/a	n/a	n/a	n/a

6. NREL/NYPA

Table IV.6.a summarizes the system's past and current year performance. Table IV.6.b summarizes solar/weather data.

During September 10-12, NREL's Byron Stafford and Bob Hansen and USSC's Jim Young performed several repairs and scheduled maintenance to the system and restarted it after a 7-month shutdown. They reinstalled one 12-module string that USSC had removed earlier this summer for in-factory tests. They also installed 15 new modules at various positions within the array to replace modules that had shown evidence of delamination and/or minor frame corrosion. Four other modules that failed a field wet megger test were disconnected but not replaced (the full array has 1,008 modules).

The entire array was cleaned thoroughly to remove a heavy accumulation of tar-like deposits, dirt, and bird droppings. It was determined that the reason for the PCU's shutdown earlier this year was not due to a ground fault as indicated but was instead caused by a loose neutral leg connection in a rooftop source circuit combiner box. Once this was corrected, the PCU started properly. Several signals were calibrated (dc and ac voltages and dc current), the POA and GHI PSPs were replaced and realigned, and a loose thermocouple was reattached.

The system ran for eight days before tripping off line briefly with another dc ground fault indication. On September 24, the unit tripped off line with the same indication and would not reset. *Later note: A field inspection by NREL early in October traced the problem to a faulty ac breaker on an indoor distribution panel. NYPA repaired the breaker and restarted the system on 10/15.*

An updated rating of 16.0 ± 0.4 kWac was calculated using data from the mid-September period after the system was restarted. This rating is considerably better than the 12.9 kW calculated by PVUSA using data from June 1995, when the array was probably heavily soiled and the instruments may have drifted out of calibration. The present rating is only 6% less than NREL's original 17 kW rating assigned using August 1993 data, which suggests a substantial portion of the initial light-induced degradation occurred over the first two months after the array was installed in June 1993. The plant's original rating will continue to be used for descriptive purposes and for calculating capacity factors, but the performance index from this quarter on will account for the expected reduced output via the degradation adjustment factor ($16.0/17.0 = 0.94$).

Table IV.6.a
NREL/NYPA Performance Summary

IPC/USSC system characteristics	
NREL Rating:	17.0 kW ac
Installation date:	7/93
Total module area:	413 m ²
Orientation:	Fixed 10° tilt, south-facing

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
Performance Index %	84	7	21	0	8
AC kWh	14,559	1,193	659	0	534
AC eff. %	3.0	2.9	2.4	n/a	3.6
Cap. fac. %	9.8	1.1	1.8	0	1.4
Max. ac kW	16.2	14.9	9.9	0	14.9
Wtd. avg. T _{module} °C	36	24	11	n/a	40
POA insol. (PCU on) kWh/m ²	1,226	109	71	0	38

Table IV.6.b
NREL/NYPA Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
POA insol. kWh/m ²	1,391	1,140	252	462	426
Horiz. insol. kWh/m ²	1,223	1,174	207	572	395
LT-Avg. horiz. insol. kWh/m ²	1,460	1,244	255	507	482
Peak POA irradi. W/m ²	1,174	1,182	1,028	1,182	1,140
Peak horiz. irradi. W/m ²	1,071	1,088	907	1,088	1,061
Min. T _{amb} °C	-13	-10	-10	2	14
Avg. T _{amb} °C	15	15	3	18	25
LT-Avg. T _{amb} °C	13	14	2	17	23
Max. T _{amb} °C	44	41	20	41	37
Avg. wind speed m/s	2.6	3.1	3.5	3.2	2.6
Max. wind speed m/s	20.3	14.4	11.7	9.7	14.4

7. SMUD

Table IV.7.a summarizes past and current year performance. Table IV.7.b summarizes solar/weather data. The system maintained its high reliability and performance again this quarter, generating 95% of the energy expected from it. There was one 3-day period from 9/27 to 9/30 when the system was off line but no errors were recorded by the DAS and there were no reported failures or maintenance activities. There was also a major grid outage on the afternoon of 8/10 over much of the western US, but it only reduced this system's generation by about 25% for that day. The surprising result for this system is that it maintained a high output during the dry summer months while the performance of the nearby Davis systems was generally reduced by at least 10% due to soiling.

Table IV.7.a
SMUD Performance Summary

UPG/SSI system characteristics	
PTC Rating:	207 kW ac
Installation date:	4/94
Total module area:	2043 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
Performance Index %	81	92	74 ²	96	95
AC kWh	384,380	372,918	56,537	154,630	161,751
AC eff. %	10.1	9.8	8.4	10.3	9.7
Cap. fac. %	21.2	27.4	12.5	34.2	35.4
Max. ac kW	240	224	217	224	206
Wtd. avg. T _{module} °C	40	43	30	42	49
POA insol. (PCU on) kWh/m ²	1,856	1,877	326	736	815

Table IV.7.b
SMUD Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
POA insol. kWh/m ²	2,184	1,985	336	800	849
[1-axis insol. est. from Davis]	[2,473]	[2,198]	[406]	[858]	[934]
Horiz. insol. kWh/m ²	1,668	1,498	265	605	628
LT-Avg. horiz. insol. kWh/m ²	1,788	1,549	279	637	633
Peak POA irradi. W/m ²	1,143	1,096	988	1,096	1,091
Peak horiz. irradi. W/m ²	1,135	1,082	1,008	1,067	1,082
Min. T _{amb} °C	1	1	1	4	9
Avg. T _{amb} °C	18	19	12	20	25
LT-Avg. T _{amb} °C	16	17	10	18	23
Max. T _{amb} °C	44	45	28	42	45
Avg. wind speed m/s	2.6	2.4	2.4	2.6	2.3
Max. wind speed m/s	19.0	16.4	16.4	11.3	8.9

² Was listed as 70% in 1st quarter 1996 report.

8. Central and South West Services (CSW)

Performance data for the Solar Park's UPG system is summarized in Table IV.8.a and data for the ENTECH system is summarized in Table IV.8.b. Weather data are summarized in Table IV.8.c. CSW reported that it rained more often than normal this summer at the Solar Park, helping ease several years of drought. The quarterly insolation was 13% less than last year (and 20% less than the El Paso long-term average). The effect of below-normal insolation on energy generation was offset somewhat by the fact that the panels were cleaner and cooler than normal (the average air temperature was 1 °C cooler than last year and 5 °C less than the normal for El Paso).

UPG

This system operated at a very high overall quarterly performance index of 97%. The only significant interruptions occurred in July, when downtime due to recurring PCU trips reduced generation over a two-week period by about 20%. Beginning in August, upgraded control firmware was installed in the PCU and it has since captured essentially all of the available POA insolation. Another maintenance item was reported in early September concerning a rash of failed row tracking motor fuses, possibly caused by transients from lightning.

ENTECH

In addition to having a technician perform a 1-hr weekly maintenance and inspection procedure, ENTECH made one major maintenance visit in July. They improved the tracking system's positioning stability by modifying its electrical braking and morning reset logic, and by adding additional batteries. They also replaced cracked lenses on four of the array's 288 modules and disconnected the PCU's smoke alarm, which had proven to be chronically sensitive to dust drawn into the PCU cabinet by its cooling fan. These changes helped the PV system achieve its highest quarterly performance index to date, 66%, despite the fact that since September 21, the system has only operated at half power. That day, one of the array's four source circuit junction boxes failed in the same way that another one had less than one year ago.

Lightning-related transients have been cited as a possible cause for these failures, but the problem may be due to a design or component flaw. In both cases, a small fire has originated at a fuse terminal, open-circuiting one of the array's two source circuit monopoles. The first box was rebuilt by CSW with larger ampacity wiring, a heavy-duty fuse block, and higher-rated fuses. This time, ENTECH is conducting a design review. Their preliminary tests show the existing Ferraz fuse block generates 75% more resistive heat at a typical 20 amp load than a comparably rated Gould block. They are also reconsidering whether MOVs may be more appropriate for surge protection than the presently used SOVs.

Table IV.8.a
CSW UPG Performance Summary

UPG/SSI system characteristics	
PTC Rating:	98 kW ac
Installation date:	11/94
Total module area:	1021.5 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
Performance Index %	63	91	98	88	97
AC kWh	148,546**	174,884**	53,263**	66,133	55,488
AC eff. %	8.5	9.2	10.6	8.9	9.0
Cap. fac. %	17.3**	27.1**	24.9**	30.9	25.6
Max. ac kW	105	106	106	106	102
Wtd. avg. T _{module} °C	38	43	31	45	46
POA insol. (PCU on) kWh/m ²	1,613	1,842	512	727	603

* March data only

** For October '95 through February '96, the kWh (and capacity factor) were estimated as [dc kWh]/[95% PCU efficiency]

Table IV.8.b
CSW ENTECH Performance Summary

ENTECH system characteristics	
PTC Rating:	83 kW ac
Installation date:	2/95
Total module area:	907 m ²
Orientation:	2-axis trk. concentrator

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
Performance Index %	n/a	44	16	56	66
AC kWh	91,602	71,810	9,729	33,437	28,644
AC eff. %	n/a	8.7	9.1	8.4	9.0
Cap. fac. %	13.8	13.2	4.8	18.4	15.6
Max. ac kW	97	93	93	93	92
Wtd. avg. T _{module} °C	n/a	43	26	44	47
POA insol. (PCU on) kWh/m ²	n/a	863	73	439	351

Table IV.8.c
Fort Davis Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96	Jul-Sep '96
UPG POA insol. kWh/m ² [Estimated 1-axis insol., El Paso long-term avg. data]	incomplete 2,272 [2,762]	2,046 [2,131]	610 [625]	808 [853]	628 [653]
Direct normal insol. kWh/m ²	2,518	1,871	665	695	511
LTAvg. dir. nrml. insol. kWh/m ²	2,445	1,923	570	746	607
Horiz. insol. kWh/m ²	1,968	1,548	434	622	492
LTAvg. horiz. insol. kWh/m ²	2,082	1,729	417	695	617
Peak 1-axis irr. W/m ²	1,349	1,321	1,128	1,250	1,321
Peak dir. nrml. irr. W/m ²	1,087	1,086	1,086	1,015	1,005
Peak horiz. irr. W/m ²	1,232	1,234	1,022	1,199	1,234
Min. T _{amb} °C	-8	-10	-10	-2	5
Avg. T _{amb} °C	16	17	10	21	21
El Paso LTAvg. T _{amb} °C	17	19	9	22	26
Max. T _{amb} °C	37	37	25	37	34
Avg. wind speed m/s	3.1	2.9	3.4	3.2	2.1
Max. wind speed m/s	18.0	18.0	18.0	13.1	11.3

9. Public Service Co. of Colorado (PSCO)

Preliminary performance data are listed in Table IV.9.a. Solar/weather data are listed in Table IV.9.b. Although the system began operating in June and ran with few interruptions during the 3rd quarter, PSCO does not consider the system to be complete yet, and a rating has not been established.

Preliminary analyses this summer indicated the rated power and daily energy were considerably below design, with deficiencies identified in the tracking system, PCUs, and source circuits. The tracking system generally received less than 85% of the insolation expected from a single-axis tracking surface inclined at a 20 degree tilt. Part of this is due to a narrow design tracking range of ± 35 degrees. Most of the shortfall, however, has been due to the tracker controller's coarse hourly update interval. In September, installer New World Power shipped PSCO a reprogrammed controller designed to reduce tracking error by updating its position every 10 minutes. PSCO was unable to get the new controller to function properly, however, and expects NWP will have to visit the site to troubleshoot the new controller.

Another significant design issue concerns the PCU's inability to peak power track at a low enough voltage whenever array temperatures reach or exceed about 45 degrees C, which occurs often during the summer. NWP plans to install new control boards within each PCU and transformers in line with each one to step down the ac mains voltage and permit lower dc voltage operation.

At least two of the array's five source circuits seem to be under-performing, and this will also require field diagnosis. As of the end of the quarter, PSCO was arranging an October troubleshooting trip with NWP to address the tracker, PCU, and source circuit issues. PSCO will request PVUSA to begin data collection for a rating once the system is accepted, but this means the official rating period will have to be deferred until March 1997, when conditions are expected to be satisfactory for rating the system accurately.

Table IV.9.a
PSCO Performance Summary

NWP/AstroPower system characteristics	
Design Rating:	22 kW ac
Installation date:	6/96
Total module area:	230 m ²
Orientation:	20° tilt single axis trkr.

Quantity	cumul. 1996	Jun 18-30 '96	Jul-Sep '96
Performance Index %	n/a	n/a	n/a
AC kWh	12,742	1,652	11,090
AC eff. %	n/a	n/a	n/a
Cap. fac. %	n/a	n/a	n/a
Max. ac kW	21	20	21
Wtd. avg. T _{module} °C	n/a	n/a	n/a
POA insol. (PCU on) kWh/m ²	n/a	n/a	n/a

Table IV.9.b
PSCO Solar/Weather Summary

Quantity	cumul. 1996	Jun 18-30 '96	Jul-Sep '96
POA insol. kWh/m ²	809	102	707
[1-axis insol. est. from Boulder]	[938]	[119]	[819]
Horiz. insol. kWh/m ²	634	90	544
LT-Avg. horiz. insol. kWh/m ²	656	90	566
Peak POA irradi. W/m ²	1,216	1,156	1,216
Peak horiz. irradi. W/m ²	1,165	1,159	1,165
Min. T _{amb} °C	-4	10	-4
Avg. T _{amb} °C	20	22	20
LT-Avg. T _{amb} °C	20	19	21
Max. T _{amb} °C	35	33	35
Avg. wind speed m/s	2.7	3.3	2.6
Max. wind speed m/s	10.9	10.9	10.9

APPENDIX A

Table A.1 summarizes rating and efficiency trend data for several systems. The table is an expanded version of one included in a long-term degradation presentation given at NREL's PV System Performance and Reliability workshop in September 1996. In this table, 1993 ratings have been added, as well as new ratings for ENTECH and IPC-Maspeth that weren't available at the time of the workshop.

For six EMT arrays, results from another way of estimating degradation are shown in the rightmost column. For this method, April and October clean array efficiency data have been quality-checked and scaled to a common 45 °C operating temperature. The degradation rate and uncertainty are calculated via a best-fit line. The uncertainties are generally large, partly because of normal measurement error but mostly because the operating histories are still relatively short and only a dozen or so data points were available for the regression. Important conclusions from the degradation evaluation include:

1. Even though the uncertainty is large, PVUSA's systems with at least three years of operation appear to be degrading at an average rate of 2%/yr. Each has degraded by at least 1%/yr., with some degrading at greater than 3%/yr.
2. For most of the systems, the degradation rates seem to be slowing compared to their first rating update. For the a-Si systems, this is an expected result, as most of the initial light-induced degradation is thought to occur over the first six months of operation.
3. The two degradation calculation methods agree well.
4. The typical 2%/yr. rate is consistent with other PV literature. If these system-level effects are real, they should be considered in lifetime economics calculations, even if the effects are too minor to alter economic decision-making.

Table A.1 Long-term degradation data for selected PVUSA systems

System	Orig. rating (kW)	New rating(s) (kW)	Elapsed time from original rating (yrs)	Annual exponential degradation rate since original rating (%)	Alternate degradation calculation: semi-annual dc efficiency trend at 45 °C (%)
SSI - Davis EMT	18.7 dc	16.8 (10/93) 16.5 (4/96)	4.75 7.25	-2.2 -1.7	-1.1±0.5
Sovonics - Davis	17.3 dc	14.5 (10/93) 13.7 (4/96)	4.3 6.8	-4.0 -3.4	-3.8±0.4
UPG	15.7 dc	13.8 (10/93) 13.2 (4/96)	3.8 6.3	-3.3 -2.7	-1.6±1.0
Sovonics - Maui	18.5 dc	16.5 (10/93)	3.9	-2.9	-1.5±1.2
Solarex	15.7 dc	14.2 (10/93) 13.7 (4/96)	3 5.5	-3.3 -2.4	-2.0±0.5
ENTECH	16.5 dc	17.0 (10/93) 15.9 (4/96)	2.5 5	+1.2 -0.7	-1±2
IPC Austin	17.9 ac	16.1 (4/96)	3	-3.5	not calc.
APS	479 ac	428 (10/93) 390 (10/94) 378 (4/96)	1 2 3.5	-11 -10 -6.5	not calc.
SSI - Kerman	498 ac	476 (4/96)	2.8	-1.6	not calc.
IPC - Davis	196 ac	191 (5/96)	2.9	-0.9	not calc.
IPC - Maspeth	17.0 ac	15.6 (8/94) 12.9 (6/95) 16.0 (9/96)	1 1.8 3.1	-8.2 -14 -1.9	not calc.