PHOTOVOLTAICS *for* UTILITY SCALE APPLICATIONS

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

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QUARTERLY TECHNICAL REPORT

Second 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 transition and project planning activities continued, but the CEC/SMUD assumption of project management duties will likely be delayed until the end of 1996 while the California Public Utilities Commission (CPUC) evaluates PG&E's filing for transferring project assets to the CEC. PG&E's efforts this quarter centered on negotiating a series of asset transfer and power exchange agreements with the CEC and preparing the CPUC filing. DOE agreed to fund basic site operations through PG&E management for this year. At the same time, a parallel agreement between SMUD and DOE for a second tier of additional new activities will be developed.

The Public Service Company of Colorado's 22-kW host system at Cherry Creek State Park in Aurora began operating on June 18, and is now the state's largest PV system. It was installed by New World Power with partial funding from UPVG's *TEAM-UP* program, and uses AstroPower modules mounted on an array of five inclined single-axis tracking structures. Data collection is ongoing.

PVUSA is now monitoring 20 systems with a combined capacity of approximately 1,800 kW. One additional 375-kW system is under construction in Yuma, AZ and is scheduled to start up in December 1996. Combined, these systems generated 0.9 million kWh during April through June, increasing the project cumulative total to 8.4 million kWh since 1989¹. Locations other than Davis are noted next to the supplier's name in Table I.1.

Table I.1
2nd Quarter 1996 PV System Performance Summary

Emerging Module Technologies	Efficiency %	Capacity Factor %	Performance Index %
Amonix	not yet rated	not yet rated	not yet rated
AstroPower	5.4 dc	27	100
ENTECH	10.7 dc	29	96
Solarex	7.6 dc	23	94
Sovonics	2.6 dc	23	100
Sovonics (Maui, HI)	3.2 dc	19	97
SCI	6.1 dc	27	98
SSI	9.6 dc	23	96
UPG	2.9 dc	25	100
Utility Scale Systems			
APS	3.3 ac	18	80
ENTECH (Fort Davis, TX)	8.4 ac	18	56
IPC	7.8 ac	34	90
IPC (Austin, TX)	7.7 ac	16	60
IPC (Farmingdale, NY)	not in operation	0	0
IPC (Maspeth, NY)	not in operation	0	0
SSI	7.0 ac	9	23
SSI (Kerman, CA)	8.3 ac	21	57
UPG (Fort Davis, TX)	8.9 ac	31	88
UPG (Sacramento, CA)	10.3 ac	34	96
NWP (Aurora, CO)	not yet rated	not yet rated	not yet rated

¹ First quarter generation for 1996 was incorrectly reported as 1.1 million kWh. The correct amount was 0.4 million kWh, and the cumulative total through March 1996 should have been reported as 7.5 million kWh.

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 June, construction on UPG's 375-kW (nominal ac power under PTC) system was well under way, with site preparation nearly complete and the tracking structure's wood poles already installed. A unique aspect of this system is that the PV system will feed a 900-kW Kenetech PCU with 4.5 MWh of battery storage operated in parallel with the PV system. The grid-tied system is designed to provide peak load shaving as well as uninterruptible power for a water treatment plant.

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

In April, PVUSA was notified by UPGV that it would be awarding its contract for *TEAM-UP* data acquisition and analysis services to another bidder. UPGV noted that PVUSA's anticipated second year costs were too high, there was insufficient cofunding or incorporation of existing assets (PVUSA did not want to mingle funds), and uneasiness about the high level of student labor proposed.

The schedule for PVUSA's other major management activity, the transition to CEC/SMUD management, is less certain, and is unlikely to be completed until late this year. Earlier this year, when it was determined that CPUC review and approval of the proposed transfer of assets to the CEC would be required, PG&E and the CEC discussed entering into a short-term licensing agreement to permit the CEC and SMUD to assume project management duties until CPUC approval was received. In May, the CEC indicated it preferred to skip the licensing agreement and focus on expediting CPUC approval and planning for future PVUSA activities.

PG&E worked extensively on the CPUC application for approval of PG&E's proposed transfer of PVUSA assets to the CEC. PVUSA received eleven letters in support of the proposed transition to include with the filing. In June, PG&E met with the CPUC's Division of Ratepayer Advocates (DRA) to brief them on the proposal. No significant issues were raised. However, PG&E's Law Department concluded that an intellectual property valuation (among other less significant items) should also be included in the filing to preempt any concerns that might lengthen the anticipated three- to four-month CPUC processing period. By the end of the quarter, PG&E was preparing to enlist outside expertise to help prepare the intellectual property valuation. (As of the first of September, the CPUC filing has not yet taken place, due to establishing the intellectual property value and finalizing contracts with the CEC for signature prior to filing.)

PG&E, CEC, SMUD, and DOE continued other planning and transition activities in parallel with the CPUC filing work. DOE agreed to keep funding the project at a minimum operations level under PG&E management for this year, while a parallel agreement between SMUD and DOE for a second tier of value-added activities was under development. (In July, a detailed project plan for the last

half of 1996 will be developed, presented to the TRC and Steering Committees, and submitted to DOE for funding.)

2. Cost Analysis and Funding Activities

PVUSA's operating expenses for the second quarter were covered by a DOE contract extension granted to PG&E at the end of March. PG&E and DOE agreed to extend PVUSA's existing funding contract through 1996 while a separate funding agreement is developed between SMUD and DOE. The core work covered by PG&E for the remainder of 1996 is estimated at roughly \$360,000. Detailed task descriptions and budget estimates are currently in progress.

Several meetings took place between PG&E and the Defense Contractors Audit Agency (DCAA) regarding the PVUSA audit. Work this quarter focused on resolving differences in A&G rate calculations.

3. Technology Transfer Activities

Publications, Conferences, and Meetings

Chuck Whitaker attended Soltech '96 in Palm Springs in March.

PVUSA's 1995 Progress Report was issued in April.

Christina Jennings presented a paper titled "PVUSA -- The First Decade of Experience," at the May 1996 IEEE Photovoltaic Specialists Conference in Washington, D.C. Also at this conference, Chuck Whitaker chaired a tutorial session on utility scale BOS issues and attended a UPVG Engineering & Specifications Work Group meeting.

In June, Tim Townsend resumed his research engineer duties at the Davis site after a three month sabbatical assisting Central and South West Services Inc. (CSW) with O&M and performance analyses at their Fort Davis, TX Solar Park host site.

Site Tours

During the second quarter of 1996, PVUSA hosted 9 tours of the Davis site for a total of 45 visitors.

III. TECHNICAL ANALYSIS - DAVIS SITE

1. System Performance

General

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.

There were no significant weather-driven irregularities in generation this quarter. In April and May, the insolation, air temperature, and wind speed matched well with their long-term averages, even though the site received twice the normal amount of rainfall. In June, the insolation was slightly (about 3%) above normal, but the generation was not, due to the opposite influences of moderately higher than normal air temperatures and significantly lower than normal wind speeds.

Although the EMT-3 Amonix array was brought on line during the fall of 1995, it has not demonstrated an ability to operate reliably or to perform at its design efficiency. The array was down for all of April and much of May due to recurring failures of its tracking hardware and control software. Although a tracker fix was implemented at the beginning of May, the present configuration continues to experience brief tracking disruptions, and the manufacturer is considering further modifications. The array's poor performance was judged by Amonix to be caused by fourteen corroded cell assemblies (receiver plates). Ten of these were replaced at the end of May, improving *relative* array efficiency about 16% between May and June, even though June operating temperatures were 5 °C higher than in May. Vent holes were also installed to address condensation problems. As the performance is still below design, Amonix may replace additional receivers in the future. PVUSA has agreed with Amonix to begin reporting performance as of July 1, 1996.

Energy

Figure III.1 tracks the monthly energy supplied by the eight Davis site EMT systems this year. 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. Insolation for each month of this quarter was within the one standard deviation of the long term average.

The monthly energy production patterns generally follow the insolation trends, except that the array energy production also reflects outages and seasonal efficiency variations.

All of the EMT systems generated at least 90% of their expected amounts for the quarter. Small departures from the expected generation pattern occurred on the Sovonics and SCI arrays. Sovonics' output was a few percent lower than normal in June due to a module junction box failure on June 12. This reduced array power by about one-eighth until the module was replaced in July (while this was only the third instance of such a failure at Davis, it has been the principal type of failure—about 50 instances—on the Maui array). SCI's output was lower than expected in June because of several PCU 'nuisance' trips and component failures, including two occasions when the PCU's ac power transducer fuse failed and one occasion when a capacitor bank wire and connector within the PCU were burned and had to be replaced.

The IPC US system's generation pattern matched the single-axis insolation trend very well, and this was the first time this system generated at least 90% of the energy expected from it over a three-month period. The APS system's quarterly performance index was only 80%. There was a significant dip in generation in June, when the system was down for most of four days due to PCU trips. Recent spot checks suggest the system has degraded to about 350 kW, whereas the current

performance index calculation assumes the system's present rating is 400 kW, down from its initial fall 1992 rating of 479 kW. The SSI system generated just 23% of its expected amount. The system experienced numerous morning PCU trips that required manual restarts and also had dc and ac fuses fail on several occasions. The most significant cause of lost generation, though, was a June 4 fire in a 4-module panel assembly that resulted in a full system shutdown for the remainder of the quarter.

Table III.1
PVUSA Davis Systems: Performance Summary

Characteristics	EMT (dc ratings)								US1 (ac ratings)		
	SSI	Sov-onics	UPG	Solarex	EN-TECH	Astro Power	SCI	Amonix	APS	IPC	SSI US-1
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	17.3	15.7	15.7	16.5	17.1	12.0	n/a	479	196	67
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	11520	2443	845

System	Quantity	1995	Cumulative 1996	Jan-Mar 1996	Apr-Jun 1996
SSI	AC kWh	27,119	14,212	5,231	8,981
	Performance Index %	92	93	88	96
	DC eff. %	9.7	9.7	9.9	9.6
	AC cap.fac. %	17.2	18.0	13.3	22.8
	Insol. kWh/m ²	1,961	966	361	605
Sovonics	AC kWh	22,489	12,428	4,417	8,011
	Performance Index %	91	97	90	100
	DC eff. %	2.5	2.4	2.1	2.6
	AC cap.fac. %	16.2	17.9	12.7	23.1
	Insol. kWh/m ²	1,961	971	364	607
UPG	AC kWh	22,464	13,085	4,904	8,181
	Performance Index %	91	100	100	100
	DC eff. %	2.9	2.9	2.9	2.9
	AC cap.fac. %	17.0	19.8	14.9	24.8
	Insol. kWh/m ²	1,956	973	354	619
Solarex	AC kWh	21,002	11,914	4,305	7,609
	Performance Index %	83	90	84	94
	DC eff. %	7.1	7.6	7.7	7.6
	AC cap.fac. %	15.9	18.1	13.1	23.1
	Insol. kWh/m ²	1,958	983	363	620
ENTECH	AC kWh	25,745	14,836	5,019	9,817
	Performance Index %	75	93	87	96
	DC eff. %	10.1	10.5	10.0	10.7
	AC cap.fac. %	18.8	21.8	14.7 (Corrected from 14.1)	28.8
	Insol. kWh/m ²	1,956	751	287	464
AstroPower	AC kWh	28,785	15,544	5,917	9,627
	Performance Index %	94	99	97	100
	DC eff. %	5.5	5.5	5.6	5.4
	AC cap.fac. %	20.4	22.1	16.3	27.4
	Insol. kWh/m ²	1,969	978	367	611
Solar Cells, Inc.	AC kWh	4,519	10,479	3,977	6,502
	Performance Index %	n/r	99	100	98
	DC eff. %	6.5	6.2	6.5	6.1
	AC cap.fac. %	14.1	21.4	16.3 (Corrected from 16.9)	26.6
	Insol. kWh/m ²	378	986	372	614
Amonix	AC kWh	5,341	7,449	1,305	6,144
	Performance Index %	n/r	n/r	n/r	n/r
	DC eff. %	n/r	n/r	n/r	n/r
	AC cap.fac. %	n/r	n/r	n/r	n/r
	Insol. kWh/m ²	333	497	116	381
APS	AC kWh	535,129	293,465	100,516	192,949
	Performance Index %	73	76	68	80
	AC eff. %	2.8	3.3	3.4	3.3
	AC cap.fac. %	12.8	14.0	9.6	18.4
	Insol. kWh/m ²	1,838	829	312	517
IPC	AC kWh	187,335	205,725	58,634	147,091
	Performance Index %	40	85	76	90
	AC eff. %	7.2	7.8	7.9	7.8
	AC cap.fac. %	10.9	24.0	13.7	34.4
	Insol. kWh/m ²	1,774	1,157	346	811
SSI	AC kWh	90,514	30,761	17,663	13,098
	Performance Index %	57	37	67	23
	AC eff. %	6.9	7.8	8.4	7.0
	AC cap.fac. %	15.4	10.5	12.1	9.0
	Insol. kWh/m ²	2,036	487	265	222

Figure III.1

Figure III.2

Efficiency

Figures III.3 and III.4 show monthly average efficiencies for 1995 and 1996 for the EMT arrays and US systems, respectively. DC efficiencies are reported for seven of the eight EMT arrays (Amonix data will be included beginning in July), 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, this quarter's efficiencies were similar but slightly lower than last year's, especially during June. Although the site received twice the normal amount of rainfall this quarter, there was no precipitation after mid-May, and the arrays were visibly soiled by mid-June. Last year, the arrays were well cleaned in mid-June by two days of rain. The Sovonics array's June efficiency dip was caused by the module junction box failure noted earlier.

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. The IPC and APS systems' efficiency trends were fairly flat, despite the fact that both systems experienced a few PCU-related problems. Almost all of the lost generation for these systems was attributed to full outages, with no effect on efficiency calculations. The SSI system, however, was down during most of May and nearly all of June due to PCU trips and dc source circuit faults. When it was running, blown fuses sometimes limited it to less than full capacity. The array has been shut down since June 4, when a failure occurred within a four-module panel/bypass diode assembly. Burning material dripping from the assembly started a grass fire. Although PVUSA determined the bypass diode wiring had been reversed, the event is being investigated further to try and determine whether the wiring irregularity was solely responsible for initiating the chain of failures. This is the fifth time that a four-module panel/diode assembly on the SSI system has failed catastrophically.

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 1995. Figure III.5 shows this year's monthly average air temperature and wind speed trends and compares them to the site's 8-year averages. Error bars of one standard deviation around the 8-year average quantities indicate typical year to year variations. The global horizontal insolation over this quarter was about the same as the long-term seasonal average, corresponding to an equivalent of over 7 peak hours per day. The 19 °C quarterly average air temperature was similar to the seasonal average of 18 ± 1 °C. The 4" of rain was about twice the seasonal normal. The average wind speed of 3.3 m/s was within the normal seasonal range of 3.4 ± 0.2 m/s ($\pm$ refers to one standard deviation of the quarterly averages).

Table III.2
Solar/Weather Summary

Insolation, kWh/m ² ; Peak Irradiance, W/m ²	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96
LT-Avg. global horizontal insolation	1,838	943	285	658
Global horizontal insolation	1,773	928	281	647
Peak 10-min. avg. irradiance	1,186	1,183	1,081	1,183
Global 30° tilt insolation	1,989	1,017	382	635
Peak 10-min. avg. irradiance	1,209	1,268	1,268	1,192
Global normal insolation	2,823	1,440	492	948
Peak 10-min. avg. irradiance	1,267	1,310	1,310	1,259
Horizontal 1-axis tracking insolation	2,603	1,324	406	918
Peak 10-min. avg. irradiance	1,236	1,181	1,080	1,181
Direct normal insolation	2,123	961	336	625
Peak 10-min. avg. irradiance	1,007	1,004	1,004	963
Minimum T _{ambient} , °C	-1.3	-1	-1	4
LT-Avg. T _{ambient} , °C	15	13	9	18
Avg. T _{ambient} , °C	16	15	11	19
Maximum T _{ambient} , °C	42	40	28	40
Avg. wind speed, m/s	3.1	3.4	3.4	3.3
Max. wind speed, m/s (sustained 10-min.)	17.8	16.1	13.8	16.1

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 following section of the report. The activities are identified as either preventive maintenance (including planned outages), or failure-related (including forced outages) activities.

Table III.3
April - June 1996 O&M Summary

O&M Type	Event	Date; Force x Time (default is 1 person)
Preventive	<u>Site-BOS:</u> Read meters and report to PG&E Power Control Dept. Check fire extinguisher, water wagon, Lift, FourTrax, and sump pump Check field safety boxes and perimeter fence Mow weeds	Monthly; 0.5 hr Monthly; 1.0 hr Quarterly; 1.5 hr 6/17-20; 37 hrs
	<u>US-1 APS:</u> Clean PCU filters, test emergency lights Semi-annual array inspection (structures, modules, wiring, switchgear)	Monthly; 0.5 hr 5/20; 1 hr
	<u>US-1 IPC:</u> Clean PCU filters, set tracker clock	Monthly; 0.5 hr
	<u>US-1 SSL:</u> Inspect array, interconnections, switches Summer transformer tap change	Monthly; 1.0 hr 4/16; 2 x 1.25 hr
	<u>EMT-1 ENTECH:</u> Inspect array, check tracker alignment, check battery Check tracker gear oil, lubricate bearings	Monthly; 0.5 hr Quarterly; 0.5 hr
	<u>EMT-1 SOLAREX:</u> Annual array inspection (interconnections, switches, dc collection box)	4/24; 0.5 hr
	<u>EMT-1 SOVONICS:</u> Annual array inspection (interconnections, switches, dc collection box)	4/24; 0.5 hr
	<u>EMT-1 SSL:</u> Annual array inspection (interconnections, switches, dc collection box)	4/24; 0.5 hr
	<u>EMT-1 UPG:</u> Annual array inspection (interconnections, switches, dc collection box)	4/24; 0.5 hr
	<u>EMT-2 ASTROPOWER:</u> Semi-annual array and BOS inspection	5/20; 0.5 hr
	<u>EMT-3 AMONIX:</u> Inspect array, check tracker alignment, check UPS Semi-annual array and BOS inspection	Monthly; 0.15 hr 4/16; 0.25 hr
	<u>EMT-3 SCI:</u> Semi-annual array and BOS inspection	4/16; 0.5 hr

Table III.3
April - June 1996 O&M Summary

O&M Type	Event	Date; Force x Time (default is 1 person)
Failure-related	<u>US-1 APS:</u> (2.5 hrs total) Replace 2 REC fuses (inv. 2,3) Bypass failed fan blower switch Reset, unit shutdown for unknown reason	4/29; 0.75 6/19; 2 x 0.5 hr 5/20, 6/14, 6/20 0.25 hr each
	<u>US-1 IPC:</u> (1.75 hrs total) Recalibrate tracker position Replace blown fuse on line inductor fan	4/29; 0.25 hrs 4/29; 1.5 hrs
	<u>US-1 SSI:</u> (16 hrs total) Reset PCU after message '58' shutdowns Replace 2 inverter fuses and repair burnt terminal Replace 2 dc source circuit fuses Shutdown, suspect failed SCR, snubber, firing board. replace 45 A inv. fuse Suspect firing board failure (OK), adjust PV ref. cell and clean connections Swap suspect firing board between idle Inv. A and active Inv. B Unspecified inverter failure Replace two 45 A dc fuses Fire originating from burned module/diode assembly	14 occasions; 0.1 hr 4/16; 0.1 hr 4/19; 0.5 hr 5/20; 1 hr 5/28; 3.5 hrs 5/30; 4 hrs 6/3; 2 hrs 6/4; 0.5 hr 6/4; 2 x 1.5 hrs
	<u>EMT-1 ENTECH:</u> (1.55 hr. total) Adjust tracker, roll position not on sun PCU synchronization errors	3 occurrences; 1.35 hrs total 4/2, 5/3; 0.1 hr each
	<u>EMT-1 SOLAREX:</u> (0.1 hr total) PCU synchronization error	6/18; 0.1 hr
	<u>EMT-1 SOVONICS:</u> (0.4 hr total) PCU synchronization errors Shutdown on dc overvoltage, troubleshoot and reset	3 occurrences; 0.1 hr each 5/23; 0.1 hr
	<u>EMT-1 SSI:</u> (1.1 hrs total) PCU synchronization errors Recalibrate maximum power tracking board	6 occurrences; 0.1 hr each 5/23; 0.5 hr
	<u>EMT-1 UPG:</u> (0.1 hr total) Reset PCU after dc overvoltage trip	5/17; 0.1 hr
	<u>EMT-3 AMONIX:</u> (18.85 hrs total) Tracker failures (control board, elev. motor, encoder, reseal connections) Replace burned PCU capacitor wire termination	5 occasions; 18.35 hrs 5/28; 0.5 hr
	<u>EMT-3 SCI:</u> (0.6 hr total) Reset PCU after excessive reverse power Excess reverse power; replace fuse F4 and replace capacitor wire	6/3; 0.1 hr 6/4; 0.5 hr

The actual time spent conducting routine maintenance during the second quarter was 49 hours. The actual time spent for conducting non-routine maintenance during the second quarter was 43 hours. Actual time spent for conducting maintenance work does not include the time spent reviewing vendor documents, consulting with vendors, planning, preparation and documentation activities. The maintenance hours reported herein only include hours by PVUSA on site personnel. The hours spent by vendors or equipment manufacturers are not included.

Nearly all of the failure-related maintenance hours were evenly divided among the Amonix and SSI US-1 systems. As during the first quarter of the year, PVUSA personnel performed significant troubleshooting and diagnostic assistance to help Amonix ready their system for full operation. The SSI US-1 system suffered repeated PCU trips and blown ac and dc fuses. Eventually, source circuit problems resulted in a fire on 6/4. The fire burned several acres of grass. PVUSA and Fire

Department personnel spent 1.5 hours extinguishing it. The system was shut down until the cause(s) are determined and the system repaired. In addition, Kenetech spent 15 hours performing warranty repairs on the IPC PCU.

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 planned, a 375-kW system in Yuma, AZ, at a U.S. Department of Defense site.

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.

Through June, three groupings of daily average global horizontal insolation are evident. The Maui and Fort Davis sites have averaged about 6 peak hours of insolation per day, up from 5 peak hours through March. The Davis, Sacramento, and Kerman sites increased from 3 peak hours through March to 5 peak hours per day through June. The Austin and Maspeth sites increased their average to 4 peak hours per day, up from 3 and 2 hours, respectively. Farmingdale data have not been available this year, but that site's insolation is usually very similar to the nearby Maspeth site.

Nine of PVUSA's 17 systems with data available have generated at least 90% of the energy expected from them at the year's midpoint, the largest number of high performing systems measured to date. Particularly noteworthy is that it 1) indicates sustained reliable operation and 2) includes several systems, such as the Davis ENTECH and Fort Davis UPG systems, that have been plagued by BOS problems in the past. Good performance has also been demonstrated by the Davis IPC and Sacramento UPG systems, which have both exceeded 85% performance indices for the year. Fair performance (in the 50% to 80% range) was achieved by the Davis APS, Austin IPC, and Kerman SSI systems, which tended to be characterized by intermittent PCU trips and PCU component failures. There were also several poor performing systems, each of which experienced PCU problems, and some of which experienced other BOS problems (module/source circuit problems at Davis SSI and Maspeth and tracker problems at Ft. Davis ENTECH and Farmingdale IPC).

The following subsections include detailed performance information for operating sites.

PVUSA SITE DATA

Status through 6/96: 20 Systems Totaling 1,800 kW

Figure IV.1.a

Figure IV.1.b

2. Kerman

Tables IV.2.a and IV.2.b summarize the system's past and current year PV system performance, solar insolation, and weather data. Unlike the first quarter, when PCU#1 experienced repeated shutdowns, PCU#2 was down for all of June and most of May. Even in April, both units averaged one nuisance trip every three days. The plant's performance index of 57% this quarter reflects the poor PCU reliability. PG&E's Fresno operators were usually able to reset the PCUs via remote control, but often the units would only run for a short time before tripping again. Fresno crews were dispatched to the site several times to troubleshoot the units. Over the past three years, these efforts have rarely been able to identify specific problems, and reseating connectors has often enabled the PCUs to restart OK. In addition, PCU#2 continued to be fed by just six of its eight source circuits. (two circuits were shut off earlier this year when their protective movistors failed, and the MOVs have not yet been replaced.)

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
Performance Index %	51	54	45	57
AC kWh (incl. '93 start-up)	586,570	312,203	78,515	233,688
AC eff. %	8.1	8.1	7.4	8.3
Cap. fac. %	13.4	14.4	7.2	21.5
Max. ac kW	498	432	364	432
Wtd. avg. T _{module} °C	40	39	34	41
POA insol. (PCU on) kWh/m ²	1,279	718	192	526

Table IV.2.b
Kerman Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96
1-axis insol. kWh/m ²	est. 2,513	est. 1,267	est. 374	est. 893
Horiz. insol. kWh/m ²	1,781	943	284	659
LT-Avg. horiz. insol. kWh/m ²	1,899	971	307	664
Peak 1-axis irradi. W/m ²	1,238	1,109	1,004	1,109
Peak horiz. insol. W/m ²	1,158	1,124	1,098	1,124
Min. T _{amb} °C	2	0	0	3
Avg. T _{amb} °C	19	18	14	21
LT-Avg. T _{amb} °C	17	16	12	21
Max. T _{amb} °C	43	42	29	42
Avg. wind speed m/s	2.6	2.9	2.4	3.4
Max. wind speed m/s	12.7	10.9	10.9	10.5

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. The system's performance index over the second quarter was 97%. In April and again in June, the array developed 60 volt and 15 volt imbalances as a result of failed modules or module connections. Based on past experience, this suggests two failed in April and one in June. PVUSA notified Maui Electric and the imbalances were fixed within a week, although Maui Electric has not reported the nature of the repairs. Maui Electric did report they have not been able to eliminate a 15 volt imbalance that occurs during the early and late hours each day, but the same characteristic has been observed on the Davis array. Midday voltages are balanced.

Assuming three more failures this quarter, the total number of modules or module connections that have failed throughout seven years of operation now stands at 56 out of 1200 modules. The number of failed modules by year from 1990 through 1996 is 13, 11, 5, 6, 9, 7, and 5.

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 153 days due to lost data)	Jan-Mar '96 (based on 62 days due to lost data)	Apr-Jun '96
Performance Index %	97	98	100	97
AC kWh	31,006	13,059	5,605	7,454
DC eff. %	3.3	3.2	3.3	3.2
Cap. fac. %	20.1	20.2	21.4	19.4
Max. ac kW	18.9	18.8	18.8	16.5
Wtd. avg. T _{module} °C	44	44	42	45
POA insol.(PCU on) kWh/m ²	2,037	875	361	514

Table IV.3.b
Maui Solar/Weather Summary

Quantity	1995	cumul. 1996 (based on 153 days due to lost data)	Jan-Mar '96 (based on 62 days due to lost data)	Apr-Jun '96
POA insol. kWh/m ²	2,139	895	376	519
Horiz. insol. kWh/m ²	2,057	888	316	572
LT-Avg. horiz. insol. kWh/m ²	2,009	1,176	600	576
Peak POA irradi. W/m ²	1,218	1,240	1,221	1,240
Peak horiz. irradi. W/m ²	1,291	1,209	1,184	1,209
Min. T _{amb} °C	15	14	14	18
Avg. T _{amb} °C	28	27	25	29
LT-Avg. T _{amb} °C	24	23	23	24
Max. T _{amb} °C (Jun-Jul '93 n/a)	42	45	45	42
Avg. wind speed m/s	3.6	3.8	4.1	3.4
Max. wind speed m/s	12.4	13.8	13.8	11.0

4. Austin

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 improved to 60% this quarter, compared to 43%² for the first quarter. Nevertheless, this year's operation has been considerably poorer than the 80% performance index average over the past two years. Historically, nuisance PCU trips have been the principal cause of lost generation for this system. No reports were received regarding maintenance activities, so it is assumed here that the low monthly energy captures of 50% in April, 70% in May, and 60% in June were the result of recurring PCU trips.

The DAS lost power on April 28 and subsequently lost its stored data and memory. PVUSA was able to reload the data logger program on April 30 after power was restored.

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
Performance Index %	77	54	43	60
AC kWh	25,732	9,079	2,973	6,106
AC eff. %	7.6	7.8	7.9	7.7
Cap. fac. %	16.4	11.6	7.6	15.6
Max. ac kW	17.6	18.4	16.8	18.4
Wtd. avg. T _{module} °C	43	42	33	46
POA insol. (PCU on) kWh/m ²	1,614	555	180	375

Table IV.4.b
Austin Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96
POA insol. kWh/m ²	1,855	1,016	391	625
Horiz. insol. kWh/m ²	1,599	797	304	493
LT-Avg. horiz. insol. kWh/m ²	1,700	892	349	543
Peak POA irradi. W/m ²	1,096	1,141	1,102	1,141
Peak horiz. irradi. W/m ²	1,129	1,177	1,006	1,177
Min. T _{amb} °C	-8	-6	-6	6
Avg. T _{amb} °C	23	22	15	29
LT-Avg. T _{amb} °C	20	18	12	24
Max. T _{amb} °C	45	44	42	44
Avg. wind speed m/s	1.7	2.4	2.2	2.6
Max. wind speed m/s	10.6	8.8	8.8	6.8

² 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 PCU, wiring, tracker, and DAS problems. In April, staff from the Florida Solar Energy Center, at NYSERDA's request, visited the site to provide an assessment. Their conclusions brought focus to the PCU and incompatibilities between the PCU and grid. NYSERDA and IPC are continuing to work out a resolution. NYSERDA is also working on obtaining funding to revamp this and three similar nearby systems, but a repair schedule is not yet 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
Performance Index %	38	n/a	n/a	n/a
AC kWh	11,084	n/a	n/a	n/a
AC eff. %	7.8	n/a	n/a	n/a
Cap. fac. %	7.1	n/a	n/a	n/a
Max. ac kW	20.9	n/a	n/a	n/a
Wtd. avg. T _{module} °C	38	n/a	n/a	n/a
POA insol. (PCU on) kWh/m ²	674	n/a	n/a	n/a

Table IV.5.b
NYSERDA Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96
POA insol. kWh/m ²	est. 1,723	n/a	n/a	n/a
Horiz. insol. kWh/m ²	est. 1,340	n/a	n/a	n/a
LT-Avg. horiz. insol. kWh/m ²	1,460	762	255	507
Peak POA irradi. W/m ²	1,080	n/a	n/a	n/a
Peak horiz. irradi. W/m ²	1,267	n/a	n/a	n/a
Min. T _{amb} °C	n/a	n/a	n/a	n/a
Avg. T _{amb} °C	n/a	n/a	n/a	n/a
LT-Avg. T _{amb} °C	13	10	2	17
Max. T _{amb} °C	n/a	n/a	n/a	n/a
Avg. wind speed m/s	1.7	n/a	n/a	n/a
Max. wind speed m/s	10.4	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.

The system has been shut down since a February 'ground fault'. USSC inspected the system in June and found several delaminating modules but could not locate any ground faults. The array was heavily soiled with many black tar-like spots on the modules. The PSP was found to be mounted about 5 degrees east of south. One string of 12 modules was removed for factory re-tests.

One module failed a factory hi-pot test, but the others tested OK. Once the modules were cleaned and the results scaled to full array size, USSC found the array should be restorable to its original power of about 19 kWdc. NREL has scheduled a trip in September to replace modules, clean the array, test its source circuits, and re-start it.

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
Performance Index %	84	7	21	0
AC kWh	14,559	659	659	0
AC eff. %	3.0	2.4	2.4	n/a
Cap. fac. %	9.8	0.9	1.8	0
Max. ac kW	16.2	9.9	9.9	0
Wtd. avg. T _{module} °C	36	11	11	n/a
POA insol. (PCU on) kWh/m ²	1,226	71	71	0

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

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96
POA insol. kWh/m ²	1,391	714	252	462
Horiz. insol. kWh/m ²	1,223	779	207	572
LT-Avg. horiz. insol. kWh/m ²	1,460	762	255	507
Peak POA irradi. W/m ²	1,174	1,182	1,028	1,182
Peak horiz. irradi. W/m ²	1,071	1,088	907	1,088
Min. T _{amb} °C	-13	-10	-10	2
Avg. T _{amb} °C	15	10	3	18
LT-Avg. T _{amb} °C	13	10	2	17
Max. T _{amb} °C	44	41	20	41
Avg. wind speed m/s	2.6	3.4	3.5	3.2
Max. wind speed m/s	20.3	11.7	11.7	9.7

7. SMUD

Table IV.7.a summarizes past and current year performance. Table IV.7.b summarizes solar/weather data. There were no reported outages or significant maintenance activities for the system this quarter and it achieved a system-record performance index of 96%. One discrepancy with this system concerns its solar data. Even though it is only 30 miles from the Davis site and has similar topography and climate, the horizontal insolation was 6.5% lower than the Davis site's. At Davis, the pyranometers are cleaned three times per week and at Hedge, the instruments are not routinely cleaned. It is unlikely that a difference of 6.5% could be related to calibration error. Sacramento's insolation may be slightly lower than Davis' due to generally poorer air quality and perhaps slightly higher humidity, but the effect of instrument soiling is probably reducing the Hedge site's readings by 3 to 5%. Interestingly, the POA instrument is not cleaned on the Davis site's 1-axis tracking IPC system, and its quarterly insolation agreed with the Hedge site's POA insolation within 1%.

Table IV.7.a includes a correction to the first quarter performance index, which was listed as 70% in the previous report.

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
Performance Index %	81	89	74	96
AC kWh	384,380	211,167	56,537	154,630
AC eff. %	10.1	9.8	8.4	10.3
Cap. fac. %	21.2	23.4	12.5	34.2
Max. ac kW	240	224	217	224
Wtd. avg. T _{module} °C	40	39	30	42
POA insol. (PCU on) kWh/m ²	1,856	1,062	326	736

Table IV.7.b
SMUD Solar/Weather Summary

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96
POA insol. kWh/m ² [1-axis insol. est. from Davis]	2,184 [2,473]	1,136 [1,264]	336 [406]	800 [858]
Horiz. insol. kWh/m ²	1,668	870	265	605
LT-Avg. horiz. insol. kWh/m ²	1,788	916	279	637
Peak POA irradi. W/m ²	1,143	1,096	988	1,096
Peak horiz. irradi. W/m ²	1,135	1,067	1,008	1,067
Min. T _{amb} °C	1	1	1	4
Avg. T _{amb} °C	18	16	12	20
LT-Avg. T _{amb} °C	16	14	10	18
Max. T _{amb} °C	44	42	28	42
Avg. wind speed m/s	2.6	2.5	2.4	2.6
Max. wind speed m/s	19.0	16.4	16.4	11.3

8. Central and South West Services (CSW)

The Fort Davis Solar Park is a well-designed showcase for PV and solar thermal technologies (an experimental solar dish concentrator from Cummins occupies part of the 10-acre site along with the two 100-kW PV systems monitored by PVUSA). The SWTDI-designed DAS has an attractive real time display that also plots the current day's power trend alongside the prior day's trend. There is an outstanding public access pavilion with renewables storyboards and a real time display of power, irradiance, and equivalent number of homes served located just outside the fenced area of the plant. Unfortunately, the site has shown a vulnerability to grid transients (usually attributed to lightning) that have damaged DAS equipment and hampered telephone/fax/modem communications.

The plant is located on a lightly-loaded 12-kV radial circuit that serves an observatory atop a nearby mountain. It has been suggested that the observatory's ground reference may not be adequate to dissipate frequent lightning strikes and that harmful transients are too often propagated along the utility's neutral. Tim Townsend assisted CSW and their operating utility, West Texas Utilities (WTU) with plant O&M and performance analyses from the end of February thru May this year, and about 50% of his efforts concerned DAS display and communications equipment repairs.

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.

UPG

Aside from occasional trips of its Omnion PCU, some of which occurred on weekends causing extended down time, this system experienced very few problems over the second quarter. It generated 88% of its expected energy. In May, after two false smoke alarm shutdowns caused by dust being drawn into the PCU by a fan, an air filter was added at the air intake plenum.

Another longstanding PCU/source circuit shedding problem was also addressed in May. To avoid a full shutdown, the PCU was designed to shed one of the array's five source circuits if the power reached 107 kW. The problem has been that the PCU tended to shed a circuit as early as 8 a.m. on cool, clear days (air temperature $\leq 18^{\circ}\text{C}$ and irradiance $\geq 1,050\text{ W/m}^2$). To prevent the system from readily reaching this value, 3/10ths of the sheddable circuit's dc fuses were removed, effectively raising the threshold overpower irradiance to at least $1,120\text{ W/m}^2$, a level only occasionally met. Consequently, the system now generates 94% of its potential output at all times instead of running at 80% of its possible output during the bulk of the midday hours.

ENTECH

The ENTECH system's performance index improved from 16% over the first three months of the year to 56% this quarter. The biggest reason was because a damaged (ground fault) source circuit that had cut array capacity by 50% since November 1995 was fixed in March. In addition, having an operator on-site to monitor the array and address tracker errors and PCU trips helped reduce the amount of down time. PCU air filters that were not effective at preventing dust-induced smoke alarm trips were modified in May (the smoke alarm was subsequently disconnected in July). Also, an ENTECH technician visited the site weekly to service and adjust tracker components.

However, the ENTECH system still suffered from chronic problems with tracker calibration, drift, and nuisance row stowing, even at moderate wind speeds as low as 15 mph. (In July, CSW noted they were working with ENTECH to improve the tracker performance, the last impediment to good system reliability.)

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
Performance Index %	63	91	98	88
AC kWh	148,546**	119,396**	53,263**	66,133
AC eff. %	8.5	9.3	10.6	8.9
Cap. fac. %	17.3**	27.9**	24.9**	30.9
Max. ac kW	105	106	106	106
Wtd. avg. T _{module} °C	38	42	31	45
POA insol. (PCU on) kWh/m ²	1,613	1,239	512	727

* 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
Performance Index %	n/a	36	16	56
AC kWh	91,602	43,166	9,729	33,437
AC eff. %	n/a	8.6	9.1	8.4
Cap. fac. %	13.8	11.9	4.8	18.4
Max. ac kW	97	93	93	93
Wtd. avg. T _{module} °C	n/a	40	26	44
POA insol. (PCU on) kWh/m ²	n/a	512	73	439

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

Quantity	1995	cumul. 1996	Jan-Mar '96	Apr-Jun '96
UPG POA insol. kWh/m ² [Estimated available 1-axis insol. using El Paso long-term avg. data]	incomplete 2,272 [2,762]	1,418 [1,478]	610 [625]	808 [853]
Direct normal insol. kWh/m ²	2,518	1,360	665	695
LT-Avg. dir. nrml. insol. kWh/m ²	2,445	1,316	570	746
Horiz. insol. kWh/m ²	1,968	1,056	434	622
LT-Avg. horiz. insol. kWh/m ²	2,082	1,112	417	695
Peak 1-axis irradi. W/m ²	1,349	1,250	1,128	1,250
Peak dir. nrml. irradi. W/m ²	1,087	1,086	1,086	1,015
Peak horiz. irradi. W/m ²	1,232	1,199	1,022	1,199
Min. T _{amb} °C	-8	-10	-10	-2
Avg. T _{amb} °C	16	16	10	21
El Paso LT-Avg. T _{amb} °C	17	16	9	22
Max. T _{amb} °C	37	37	25	37
Avg. wind speed m/s	3.1	3.3	3.4	3.2
Max. wind speed m/s	18.0	18.0	18.0	13.1

9. Public Service Co. of Colorado (PSCO)

The Public Service Company of Colorado's 22-kW host system at Cherry Creek State Park in Aurora began operating on June 18, and is now the state's largest PV system. It was installed by New World Power with partial funding from UPVG's *TEAM-UP* program, and uses AstroPower single-crystal silicon modules mounted on an array of five 20° inclined single-axis tracking structures.

PVUSA assisted PSCO with PV system and DAS design issues. In April, PSCO began construction and hired SWTDI to install the PVUSA-provided DAS. PVUSA procured pyranometers, meteorological equipment, and a Campbell data logger. The DAS enclosure and internal assembly were shipped to PSCO by the end of the month. During May, PVUSA and SWTDI worked on finalizing the data logger program. The DAS was fully operational at the time of system start-up in June, and data collection is ongoing.

After PSCO's dedication ceremony, two minor glitches in system operation were noted. One of the five tracking units wasn't operating and one source circuit was producing considerably less power than the others. By the end of June, the system was fully operational once New World Power installed a new tracker actuator and AstroPower repaired some faulty wiring and diodes on the low performing source circuit.

Some performance data were available as of the end of June. Between the June 18 start date and the end of the month, the system generated 1,652 kWh, equivalent to a capacity factor of 24% for a 22-kW system. The ac efficiency was only 7.0%, considered low for a system composed of single-crystal silicon modules, but the defective tracker was partly responsible for the apparent poor efficiency. Another tracking issue that will be studied in more detail during the third quarter is the effect of tracker rotation limits and periodic, rather than continuous, tracker movement: the first few weeks' data indicated the gain in insolation relative to a fixed horizontal orientation ranged from 16 to 20%, while long-term data from NREL suggest the gain for an ideal tracker would be about 36%.

PSCO will request PVUSA to begin data collection for the purpose of rating the system once the system once the source circuit and tracking issues have been resolved. PVUSA anticipates the conditions for rating the system should be adequate through October; otherwise, the rating period may need to be deferred until at least March 1997.