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SUSTAINED UTILITY IMPLIMENTATION OF PHOTOVOLTAICS

TEAM-UP Pre-Cursor Project, 1994/95

Final Report

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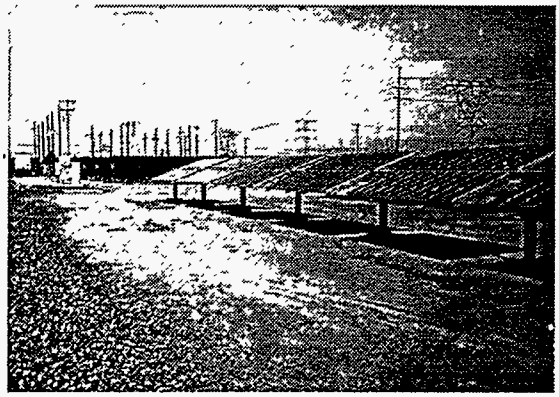

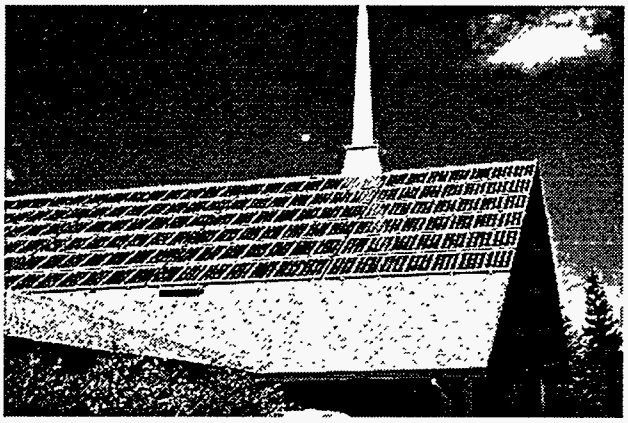
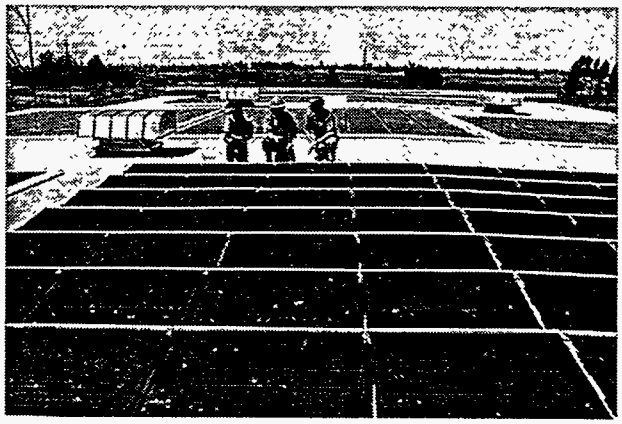

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SMUD's TEAM-UP Pre-Cursor Project, 1994/95

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Acknowledgments

The author would like to thank John Meeker, Wil Webb and Bob Martin of the DOE Golden Field Office and Jim Rannels at DOE Headquarters. Their cooperation, flexibility, and forbearance made the contracting process and the conduct of the contract possible and effective. Without the outstanding efforts and contributions of SMUD Solar staffers - Dave Collier, Ken Miller and Pete Gerlach and SMUD Interns (who served at various times through out this contract) Todd Jonas, Malissa Brine, Janna Frye, Arnold Techavimol and Walter Frey - this project would not have succeeded. The fine folk at PVUSA deserve special mention for technical support to SMUD and the rest of the utility and PV industries. The success of SMUD's procurements and installations are a direct extension of the valuable work done and the lessons learned at PVUSA.

The PV Supplier team members: Solec, Bell Products, Advanced Photovoltaic Systems, Utility Power Group, Siemens Solar, Resources Management International, Solarex, Placer Electric, Powerlight, Omnion, Pacific, and Kenetech Inverters (now Trace Technologies) all did an outstanding job in both meeting our contracts and requirements and in pushing the PV envelope forward.

Finally a special thank you for vision and support to SMUD General Managers Dave Freeman (now General Manager at LA Department of Water and Power), Jan Schori, and the publicly elected members of the SMUD Board of Directors who have seen the vision of the role of "municipal values" in defining business strategies for the public utility of the 21st Century. They have consistently reaffirmed the role of PV as a key business element in our service to our customers and to our community. Their efforts and support are making "the Bridge to the Solar Century" a reality.

Executive Summary

SMUD is a leader in utility grid-connected applications of PVs with the world's largest distributed PV power system. SMUD is continuing its ambitious sustained, orderly development (SOD) commercialization effort of the grid-connected, utility PV market. This program is aimed at developing the experience needed to successfully integrate PV as distributed generation into the utility system, develop market and long-term business strategies and to stimulate the collaborative processes needed to accelerate the cost-reductions necessary for PV to be cost-competitive in these applications by about the year 2002. This report documents the progress made in the 1994/1995 SMUD PV Program under this contract and the PV projects partially supported by this contract. This contract has been considered a "Pre-cursor" to the TEAM-UP program implemented the following year.

The 1994/95 SMUD PV program installed 988 kW (1013 kW,EPF) of grid-connected PV in four blocks. These are;

Block I:	Residential PV Pioneer Systems - 487 kW in 125 systems
Block II:	Neighborhood PV Pioneer Systems - 144 kW in 8 systems
Block III:	Substation PV Systems - 317 kW (342 kW.EPF) in 3 systems
Block IV:	Building Integrated PV (BIPV) System - 40 kW roof integrated system
TOTAL:	988 kW (1013 kW, EPF) in 137 systems

Customers want solar and they expect energy suppliers as well as government to find ways to provide solar such that it is both affordable (does not have to be lowest cost but at least able to be afforded) and low hassle.

Sustained Orderly Development works as a commercialization strategy for grid-connected PV and is a very effective lever. PV works and works well. This is especially true when a large number of like systems are installed within the same time frame and you get well up on the learning curve. Sandia studied the performance of 100 of the PV Pioneer systems during the period 8/96 through 7/97 and found an availability factor of 96% typical. Reliability increases with high volume.

PV systems work and they work very well. PV system reliability goes up as volume of installations goes up. PV modules are very reliable, though a better job needs to be done on rating modules (as well as systems). The grid-protection provided by modern, line-synchronous inverters is both adequate and reliable. Inverters continue to be the source of nearly all of the problems with PV systems. Inverters have improved considerably but remain the weak link. "Nuisance trips" are the biggest problem.

Residential and neighborhood PV systems can be adequately monitored with standard utility revenue meters that are read once a month with the service revenue meters. This presents a one time cost of less than $100 instead of the $3000+ cost of a DAS with monthly phone line costs.

Roof integrated PV systems are clearly desirable and are likely the most cost effective deployment of PV systems in the future.

A large PV program installing a hundred or more PV systems takes nearly the same amount of staff time, effort and overhead as just installing a few demonstration projects. Thus the administration costs per installed Watt is greatly reduced for a large PV Program.

For more information on the SMUD Solar Program please see our web site at: www.smud.org/energy/solar

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Introduction to the Project

The Sacramento Municipal Utility District (SMUD) is the fifth largest public utility in the nation and serves a 900 square mile area in and near Sacramento County, California. SMUD's mission, as a customer owned utility, is to meet the electric and energy service needs of our customers in a safe, reliable, economic and environmentally responsible manner. The municipal values that SMUD is founded on are the foundations of the new SMUD competitive business strategy, a strategy that incorporates the continued sustained, orderly development and commercialization of photovoltaics (PV) as a core element leading to a sustainable business opportunity. Investments made in solar power today are expected to provide the customer-owners of SMUD with substantial long-term energy and community benefits.

SMUD is a leader in utility grid-connected applications of PVs with the world's largest distributed PV power system. SMUD is continuing its ambitious Sustained, Orderly Development (SOD) commercialization effort of the grid-connected, utility PV market. This program is aimed at developing the experience needed to successfully integrate PV as distributed generation into the utility system, develop market and long-term business strategies and to stimulate the collaborative processes needed to accelerate the cost-reductions necessary for PV to be cost-competitive in these applications by about the year 2002. This report documents the progress made in the 1994/1995 SMUD PV Program under this contract and the PV projects partially supported by this contract.

This contract has been considered a "Pre-cursor" to the TEAM-UP program implemented the following year.

Project Design and Procurement

The Statement of Work Scope and Objective was:

> This procurement involves cost sharing with the Sacramento Municipal Utility District (SMUD) on the hardware, installation and evaluation of utility, grid-connected photovoltaic systems for residential, commercial/utility sized (substation), and building-integrated applications. The sustained orderly development effort by SMUD to advance the commercialization of grid-connected photovoltaics plans will include the installation of about 900 kW of grid-connected PV systems. This will include about 100 residential "PV Pioneer" applications, several systems of the commercial/utility size, and building-integrated applications such as PV integrated as architectural building components and demand-side management applications.

The 1994/95 SMUD PV program installed 988 kW (1013 kW,EPF) of grid-connected PV in four blocks. These are;

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TOTAL:	988 kW (1013 kW, EPF) in 137 systems

Rating of PV Systems

SMUD has adopted the convention of rating the effective kW output of grid-connected PV systems based on national utility standards. All PV systems, unless otherwise noted, are rated based on the AC output of the system at PVUSA test conditions (PTC). PTC ratings are typically 10% more conservative than the Standard Test Conditions (STC) ratings used by the PV industry and better reflect actual operating conditions and performance.

To account for the differences in energy potential between fixed and tracking PV systems, the Energy Potential Factor, (EPF), has been adopted. Established by the Utility PhotoVoltaic Group (UPVG), the EPF factor permits a more appropriate comparison between fixed and tracking systems. This permits the conventional comparison of $/W to attach value to the additional energy production value of tracking. SMUD rates tracking PV systems based on the AC, PTC, EPF output of the system.

Project Team Development

The project team consisted of Donald E. Osborn, Project Manager and Supervisor of the SMUD Solar Program, Dave Collier, Project Engineer and Ken Miller, Project Technician. Peter Gerlach joined later in the project to provide contract and reporting support. SMUD Engineering Interns (who served at various times through out this contract) Todd Jonas, Malissa Brine, Janna Frye, Arnold Techavimol and Walter Frey provided data analysis, customer support and general and unflagging assistance. Supplier team members included: Solec, Bell Products, Advanced Photovoltaic Systems, Utility Power Group, Siemens Solar, Resources Management International, Solarex, Placer Electric, Powerlight, Omnion, Pacific, and Kenetech Inverters.

Project Development

The SMUD Solar Program is the leading component of a nationwide collaborative effort to accelerate the cost-reductions necessary for PV to be successful on the competitive utility market. SMUD has developed the PV Pioneer Program and at the same time, SMUD has developed and pursued the installation of commercial rooftop, sub-station and parking lot systems, ranging from 4 to 130 kW. The effort under this contract was divided into 4 project areas:

Residential PV Pioneer Project

The SMUD PV Pioneer Project is a partnership with customers willing to assist in the early adoption of photovoltaic technology. SMUD purchased, owns, installed and operates the residential rooftop systems. SMUD customers participating are volunteering to share in this effort by providing the roof area to place environmentally friendly, solar electric generation PV systems. The 3-4 kW residential rooftop PV system feeds directly into the SMUD electric grid. Under this contract, the PV Pioneer Program added 125 residential systems totaling 487 kW. Today SMUD has over 2 MW on the roofs of more than 400 homes and on churches and other neighborhood/commercial buildings.

SMUD residential customers (the residential PV Pioneers) volunteer to share in this effort through a form of "green pricing" and by providing the roof area to place the environmentally friendly, solar electric generation PV systems. The PV Pioneer pays a $4 per month premium (about 10% of the average electric bill) on their utility bill to participate. In doing so, the PV Pioneers have the satisfaction of generating clean, renewable energy on their own rooftops. SMUD gains experience in the installation, operation, maintenance, pricing strategies and other aspects of residential PV systems and obtains low-cost "power plant sites." This joint effort also helps accelerate the commercialization of PV as part of a process of sustained, orderly development.

Neighborhood/Commercial Building Sited PV Systems

SMUD PV Pioneer systems are also being installed on commercial and community building rooftops. These neighborhood PV Pioneers include a VFW Hall, two local community development agencies and several churches. Churches and various other community buildings continue to offer valuable sites for the neighborhood PV Pioneer systems.

Utility Substation, Medium Size Distribution Size Generation

SMUD has installed three medium size utility substation application PV systems, Hedge PV2,3, and 4. These systems are sized just over 100 kW. The installations demonstrate the ability and versatility of placing medium size PV systems for distributed generation benefits. The three PV power stations at the Hedge site totaling an additional 317 kW were installed under the 1994 program and completed in 1995. Bell Products, Inc. and Advanced Photovoltaic Systems, Inc. supplied a fixed, 108 kW system using the APS thin-film module and a Kenetech inverter at a cost of $6.68/W. Resource Management International and Solarex supplied a fixed, 102 kW system

using Solarex modules and a Kenetech inverter at a cost of $7.35/W. UPG and Siemens Solar supplied a 132 kW, EPF (107 kW nominal) single axis tracking system using Siemens modules and multiple UPG inverters at a cost of $7.50/W, nominal or $6.10/W EPF. Each row is a modular, self contained unit with its own inverter and tracking system. This reduces the design and engineering costs for new systems.

Building Integrated PV (BIPV) System

The 1994 PV Program installed a 3 kW building integrated PV demonstration system in partnership with the Western Area Power Administration. The PV system is integrated in the reroofing structure installed on a WAPA office building. The PV roofing tile system is part of the roofing system installed to insulate and protect the roof membrane. The "Powerguard" PV system is designed and installed by Powerlight Corporation and Western Single Ply, a commercial roofing contractor. A full size, 40 kW system was installed in 1996 on the WAPA Elverta Substation control building.

PV System Installation, Testing, Operation

Project: PV Pioneers '94

System Information

Module Manufacturer:	Solec
Inverter Manufacturer:	Omnion 2200/2400
Installer:	Placer Electric
# of Systems:	119 systems at 99 sites
Rating per System:	3-4kW
Test Rating per System:	3-4kW
Total # of kW:	
Rating	400kW
Test Rating	400kW
Installation:	1994-95

System Description:

- Roof mounted PV systems on pitched composition shingled roofs
- Fixed angle arrays facing true south to true west
- Rail and footing joint mounting structure lag bolted through roofing into minimum 1/2 inch CDX plywood
- 2 600V source circuits feed a 4 kW Omnion inverter to a 120V service connection
- 7 modules/panel, 4 panels/source circuit, 2 source circuits/4kW system

- 28 modules in series make up each source circuit
- 119 systems at 99 sites ranging in size from 2.4 to 9kW
- Total of 6098 SQ-80 Solec single crystal modules

Sys Problems/Resolutions:

- 15% Failure rate with Omnion 2200 and 2400 systems. The Omnion 2400 inverters received new control boards in 1997.

History of Operation

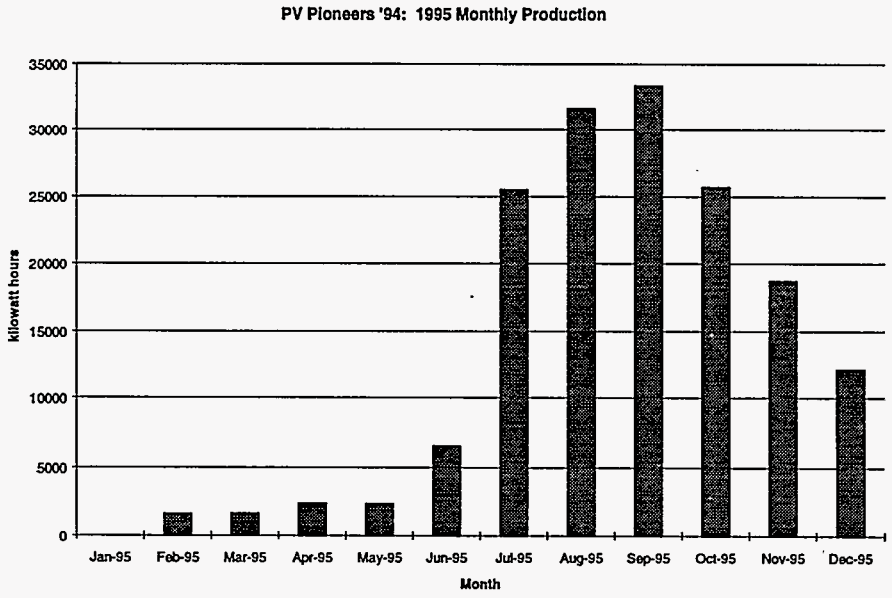
Total kWh Produced: 679,610 **(start up - April 30, 1997)**

Monthly Cap Factors: Cap factors are only available for production in 1995.

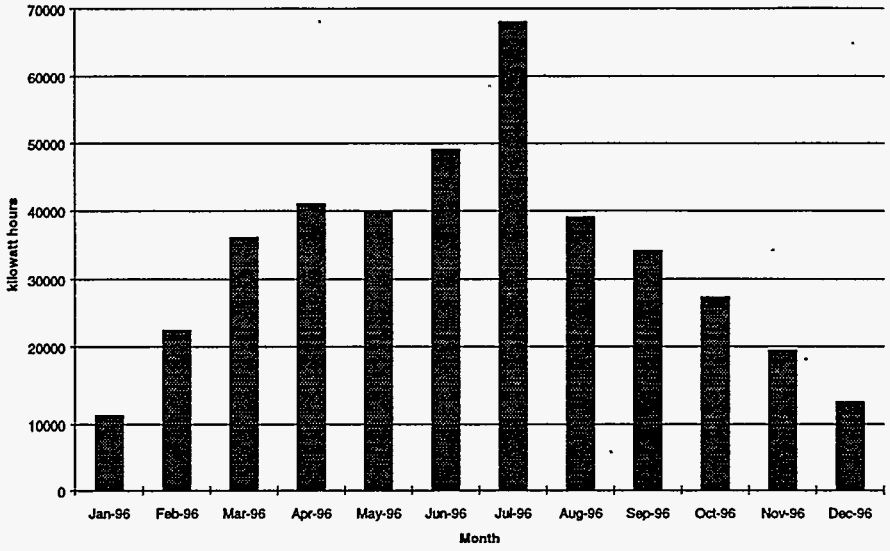
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'95		12.4%	10.7%	15.5%	14.2%	19.2%	17.6%	13.7%	12.9%	9.0%	5.6%	5.4%

Monthly Energy Production (kWh):

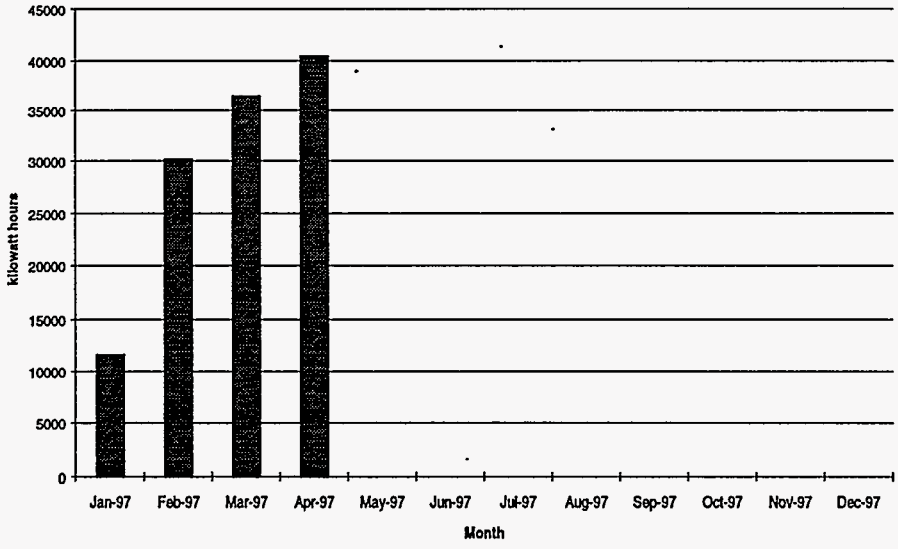
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'95	0	1620	1645	2395	2372	6513	25468	31619	33372	25654	18685	12127
'96	11047	22320	36010	40950	39967	49002	67989	39007	34027	27173	19383	12667
'97	11604	30152	36400	40442								



PV Pioneers '94: 1996 Monthly Production



PV Pioneers '94: 1997 Monthly Production Through April '97



Project: PV Pioneers '94/'95

System Information

Module Manufacturer:	Solarex
Inverter Manufacturer:	Pacific
Installer:	RMI/Placer Electric
# of Systems:	25
Rating per System:	3.5kW
Test Rating per System:	3.5kW
Total # of kW:	
Rating	87kW
Test Rating	87kW
Installation:	1994-95

System Description:

- Roof mounted PV systems on pitched composition shingled roofs
- Fixed angle arrays facing true south to true west
- Rail and footing mounting structure lag bolted through roofing into minimum 1/2 inch CDX plywood
- 22-48V source circuits feed a 4 kW Pacific inverter to a 240V service connection
- 6 modules/panel, 2 source circuit/panel, 22 source circuits/3.5kW system
- 3 modules in series make up each source circuit
- 25 systems at 25 sites all 3.5kW in size
- Total of 6098 MSX-64 Solarex polycrystalline modules

Sys Problems/Resolutions:

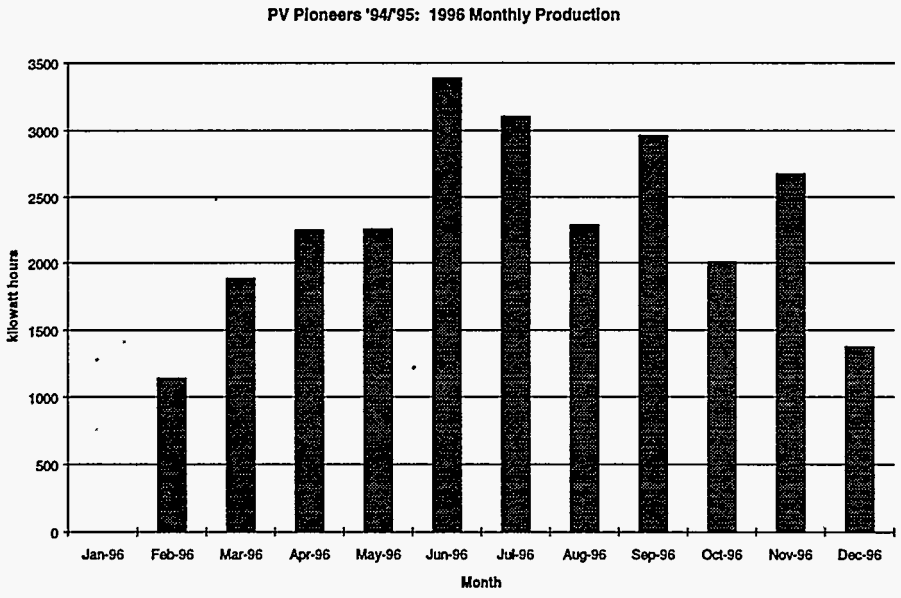
- 20% failure rate with the Pacific PCUs. Currently researching the problem with the manufacturer: Pacific Inverters

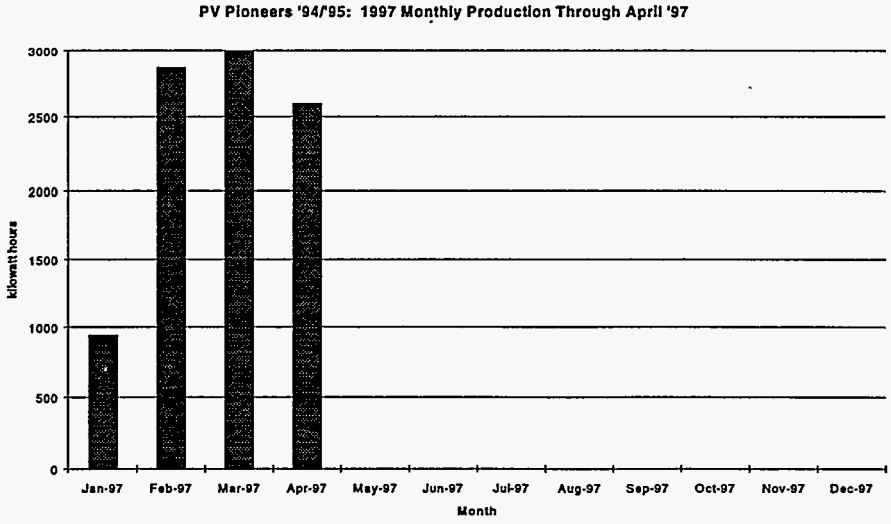
History of Operation

Total kWh produced: 34,666 **(start up - April 30, 1997)**
Monthly Cap Factors: Cap Factors are only available for production in 1995

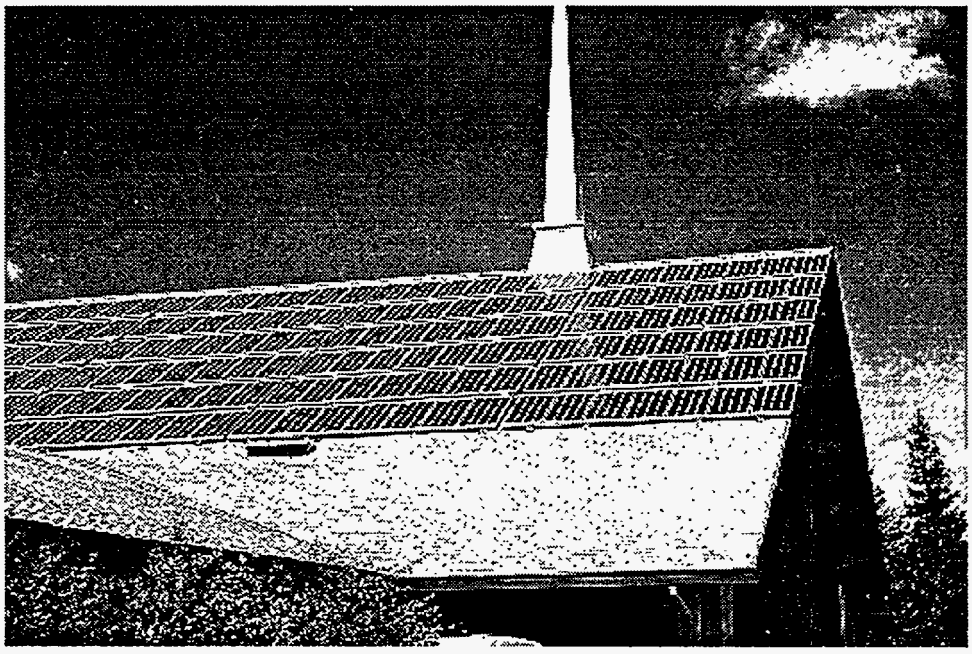
Monthly Energy Production (kWh):

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'96	0	1136	1881	2244	2251	3383	3101	2283	2959	2002	2674	1369
'97	939	2864	2990	2590								





Project: PV Pioneers Commercial '94



System Information

Module Manufacturer:	Solec
Inverter Manufacturer:	Omnion Model 2400 (6kW)
Installer:	Placer Electric
# of Systems:	24 6kW systems at 8 sites
Rating per System:	6kW
Test Rating per System:	6kW
Total # of kW	
Rating	144kW
Test Rating	144kW
Installation:	1994-95

System Description:

- Roof mounted PV systems on pitched composition shingled roofs
- Fixed angle arrays facing true south to true west
- Rail and footing joint mounting structure lag bolted through roofing into minimum 1/2 inch CDX plywood
- 3 600V source circuits feed a 6 kW Omnion inverter to a 120V service connection
- 28 SQ-80 modules in series make up each source circuit
- 24 systems at 8 sites ranging in size from 12 to 36 kW

- Total of 2016 Solec SQ-80 single crystal modules
- Typically used multiple systems per site to make up larger system size.

Sys Problems/Resolutions:

- 15% Failure rate with Omnion 2400 systems. The Omnion 2400 inverters received new control boards in 1997.

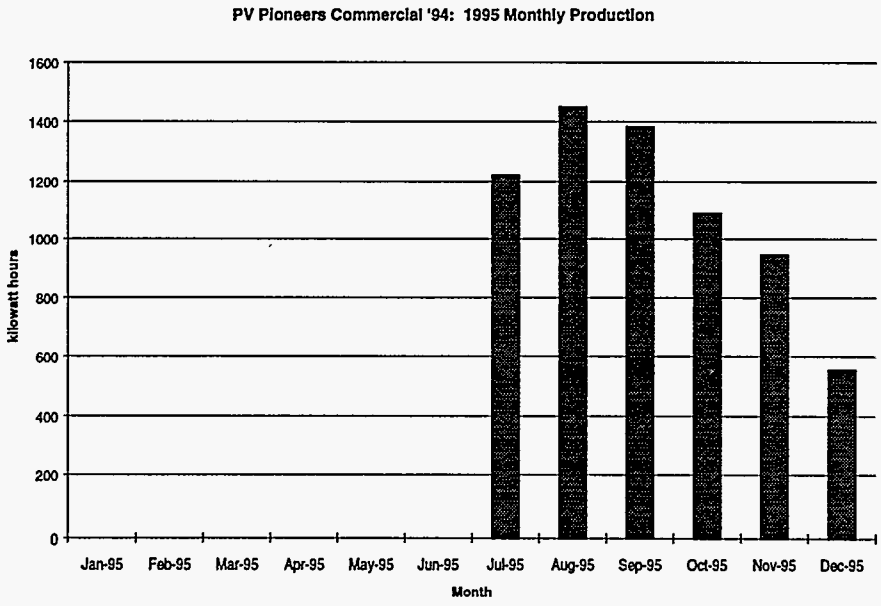
History of Operation

Total kWh Produced: 158,913 **(start up - April 30, 1997)**
Monthly Cap Factors: Cap factors are only available for production in 1995.

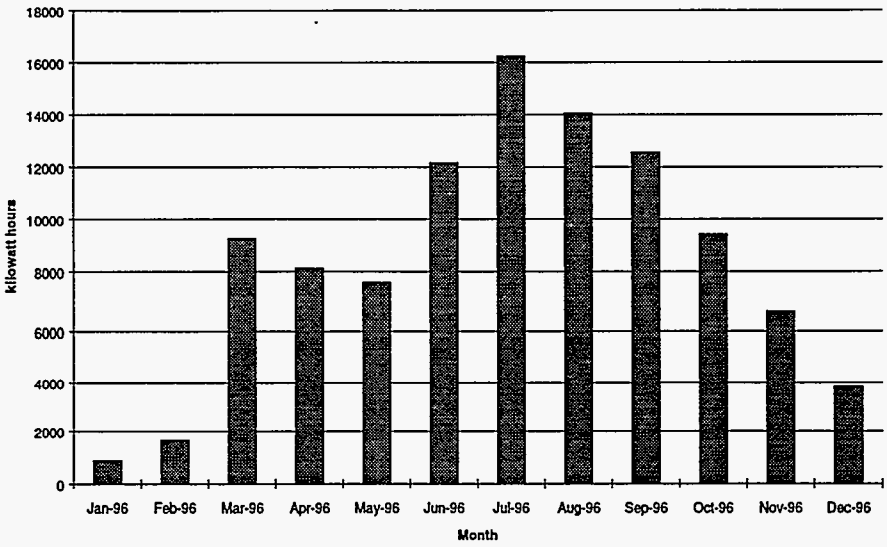
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'95							7.1%	8.1%	7.8%	5.7%	4.2%	3.7%

Monthly Energy Production (kWh):

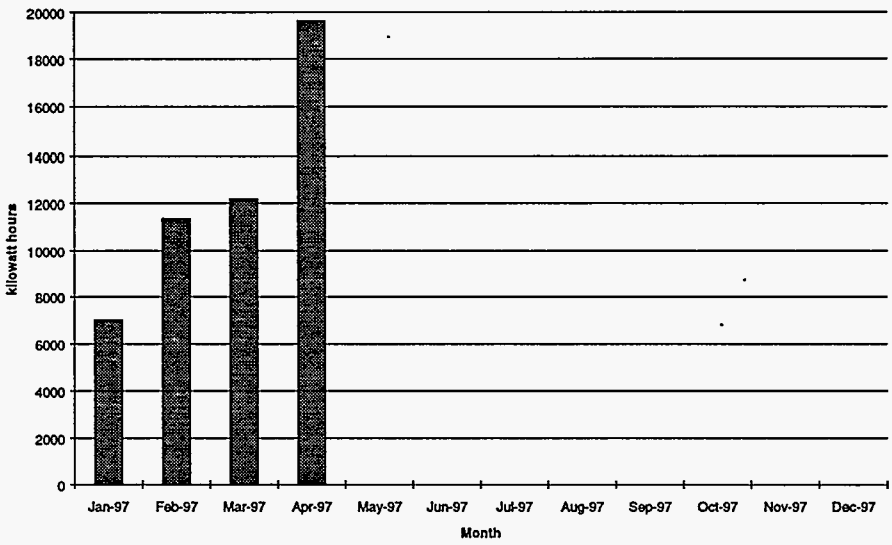
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'95							1220	1449	1383	1089	944	554
'96	833	1625	9221	8102	7599	12142	16217	14037	12538	9396	6624	3836
'97	7001	11344	12153	19606								



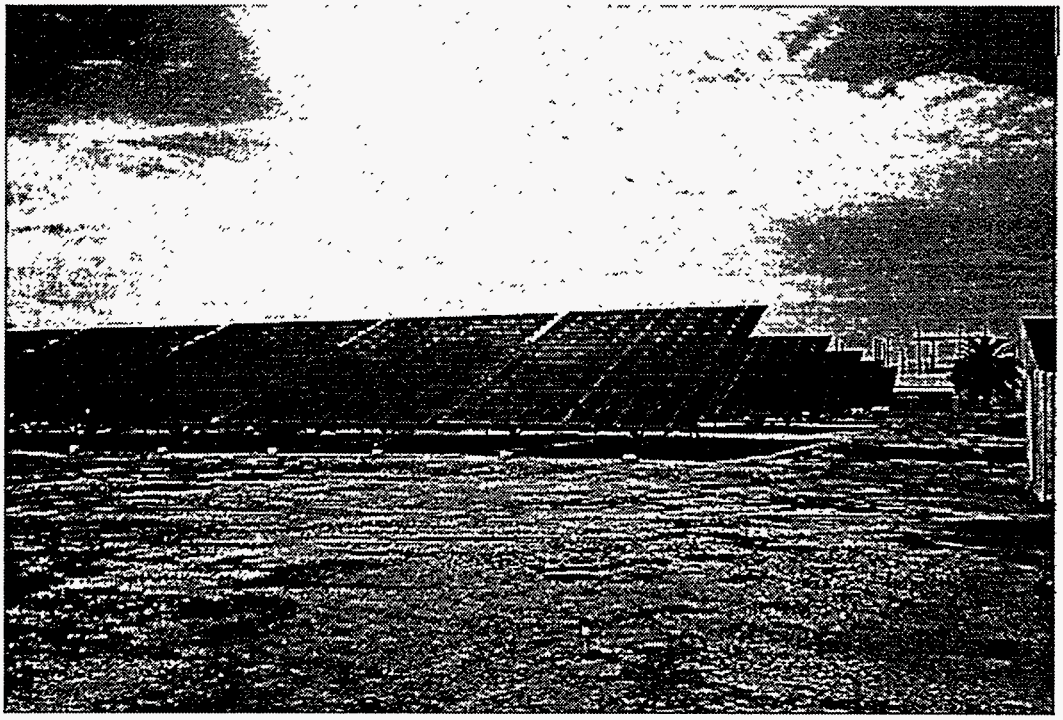
PV Pioneers Commercial '94: 1996 Monthly Production



PV Pioneers Commercial '94: 1997 Monthly Production Through April '97



Project: Hedge PV2 (APS)



System Information

Module Manufacturer:	APS
Inverter Manufacturer:	Kenetech
Installer:	Bell
# of Systems:	1
Rating per System:	108kW
Test Rating per System:	108kW
Total # of kW	
Rating	108kW
Test Rating	108kW
Installation:	1994-95

System Description:

- Ground mounted PV system on two acres of level land
- 20 degree fixed angle array facing true south
- Latus mounting structure on concrete footings
- 24-360V source circuits feed a 108kW Kenetech inverter to a 480/12kV transformer
- 4 parallel strings of 10 EP-50 modules in series make up each half source circuit
- Total of 1920 EP-50 APS single junction amorphous thin film modules

Sys Problems/Resolutions:

- One bridge failure promptly repaired by a Kenetech technician. Problem traced to a wiring error at startup testing.

History of Operation

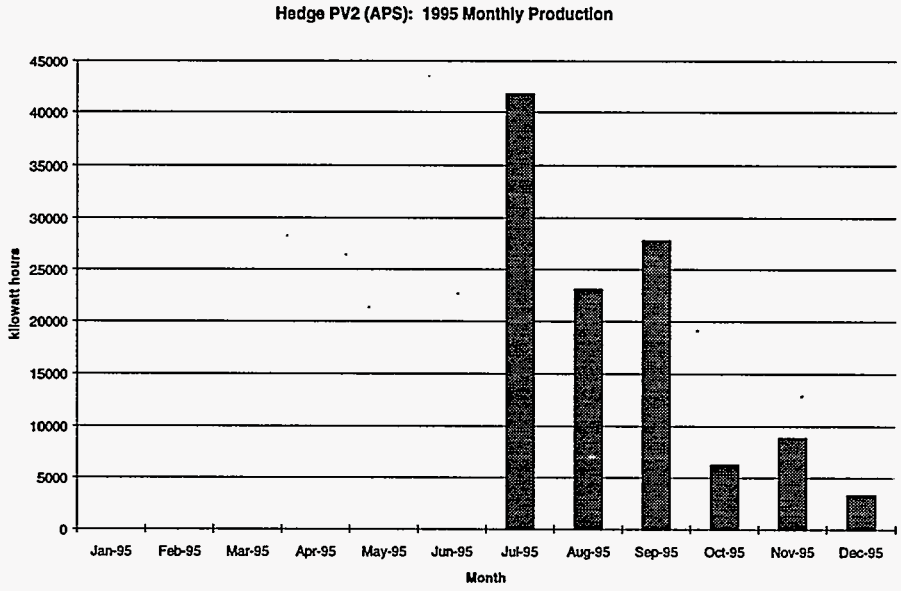
Total kWh Produced: 313,176 **(start up - April 4, 1997)**

Monthly Capacity Factors: Capacity factors are only available for production in 1995.

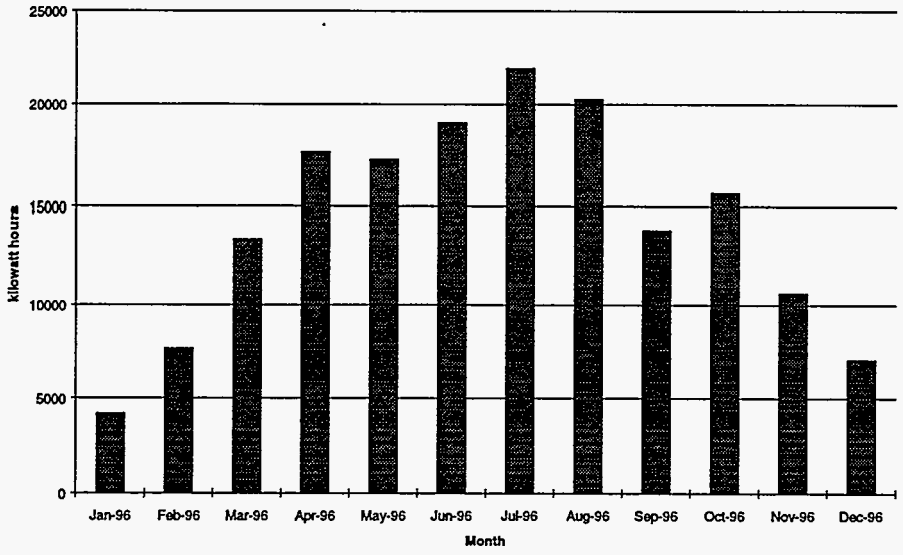
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'95							17.2%	28.6%	23.3%	7.2%	8.7%	4.9%

Monthly Energy Production (kWh):

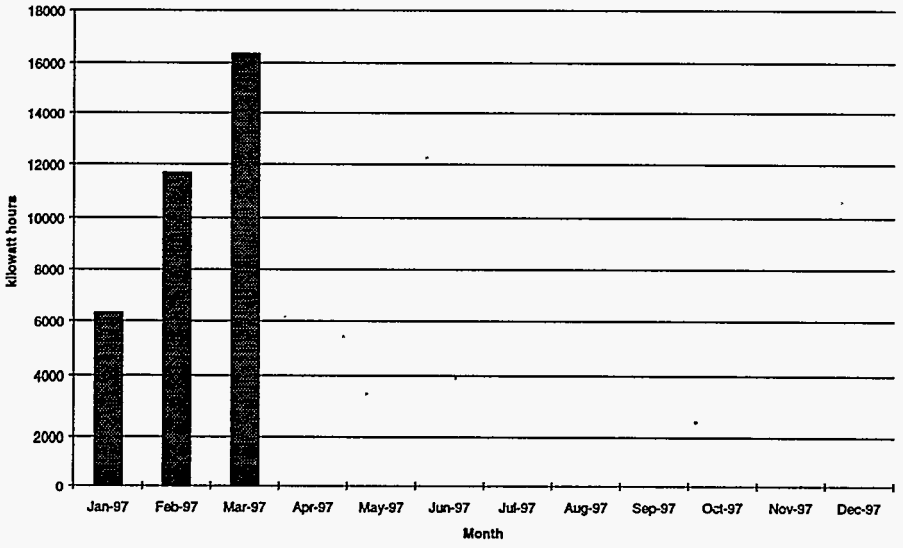
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'95							41710	23071	27778	6232	8862	3298
'96	4172	7620	13457	17480	17090	18988	21856	20234	13888	15552	10598	6998
'97	6298	11664	16330									



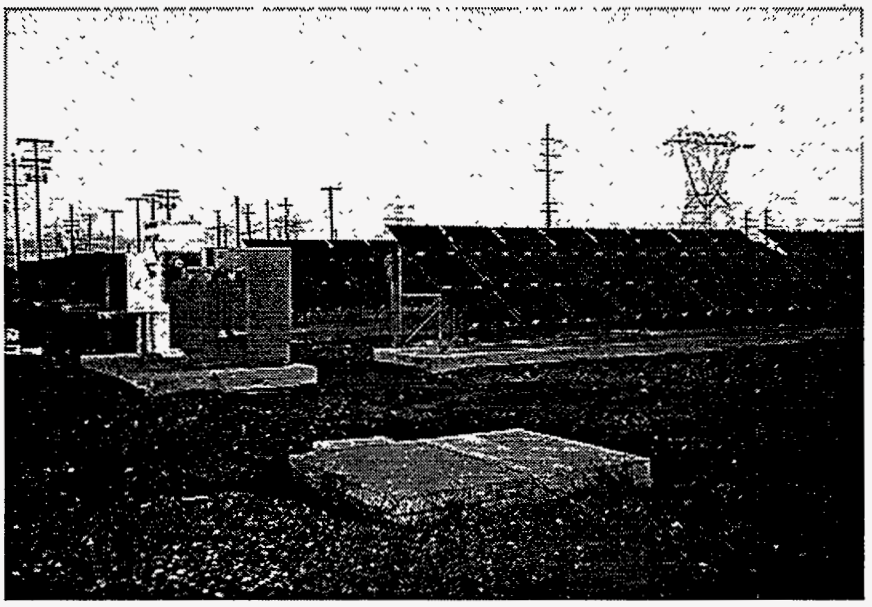
Hedge PV2 (APS): 1996 Monthly Production



Hedge PV2 (APS): 1997 Monthly Production through 4/4/97



Project: Hedge PV3 (Solarex)



System Information

Module Manufacturer:	Solarex
Inverter Manufacturer:	Kenetech
Installer:	RMI
# of Systems:	1
Rating per System:	102kW
Test Rating per System:	94kW
Total # of kW	
Rating	102kW
Test Rating	94kW
Installation:	1994-95

System Description:

- Ground mounted PV system on one acre of level land
- 30 degree fixed angle array facing true south
- Pipe joint mounting structure imbedded in concrete "ballast" footing
- 14 360V source circuits feed a 100kW Kenetech inverter to a 480/12kV transformer
- 3 parallel strings of 12 MSX-120 modules in series make up each half source circuit
- Total of 1008 MSX-120 Solarex polycrystalline modules

Sys Problems/Resolutions:

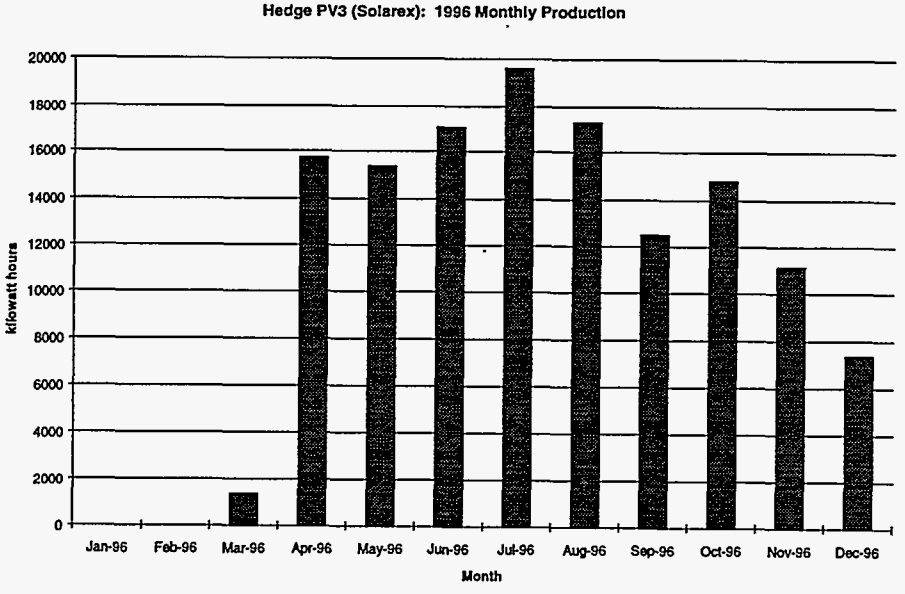
- PV modules mounted with double stick 3M tape failed to stick. Silicon Adhesive added to module mounting. Problem traced to poor preparation for mounting.
- PV modules failed wet megar testing. Problem traced to Tedlar backing was too thin which resulted in damage in handling at factory. Pin holes in Tedlar backing patched.

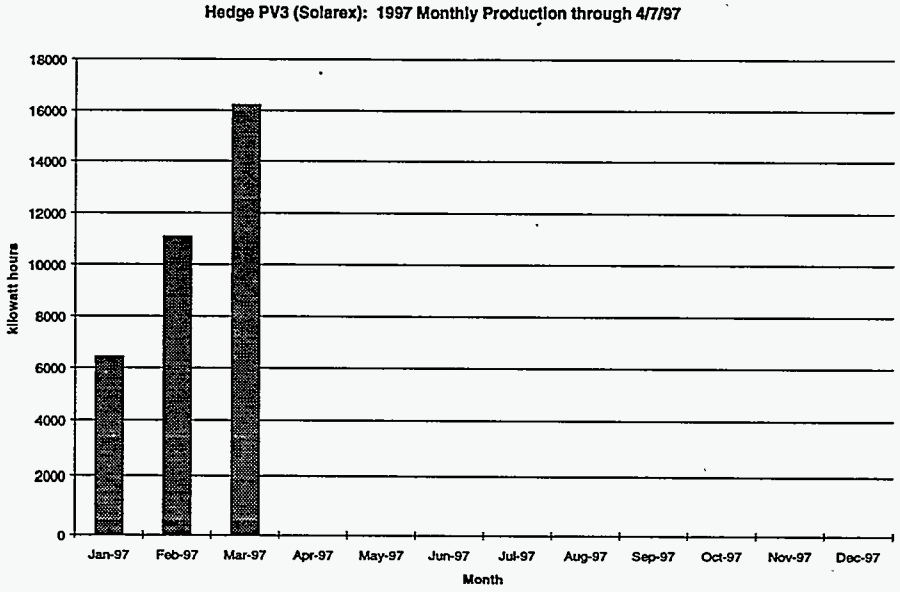
History of Operation

Total kWh produced: 165,791 **(start up - April 7, 1997)**
Monthly Cap Factors: Cap Factors are only available for production in 1995.

Monthly Energy Production (kWh):

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'96			1353	15715	15340	17046	19604	17275	12502	14774	11127	7348
'97	6424	11080	16203									




Hedge PV3 (Solarex): 1997 Monthly Production through 4/7/97
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
kilowatt hours
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
Month

Project: Hedge PV4

System Information

Module Manufacturer:	Siemens
Inverter Manufacturer:	UPG
Installer:	UPG
# of Systems:	1
Rating per System:	107kW
Test Rating per System:	107kW
Total # of kW	
Rating	107kW
Test Rating	107kW
Installation:	1994-95

System Description:

- Ground mounted PV system on one acre of level land
- single axis tracking with a north south orientation
- wood pole mounting structure with no concrete footing
- integrated power processing inverter with tracker controlled screw jack
- 26 170V source circuits feed a 15kW UPG inverter to a 480/12kV transformer
- 26 parallel strings of 11 M-55 Siemens modules in series make up each source circuit
- Total of 2288 M0-55 Siemens single crystal modules

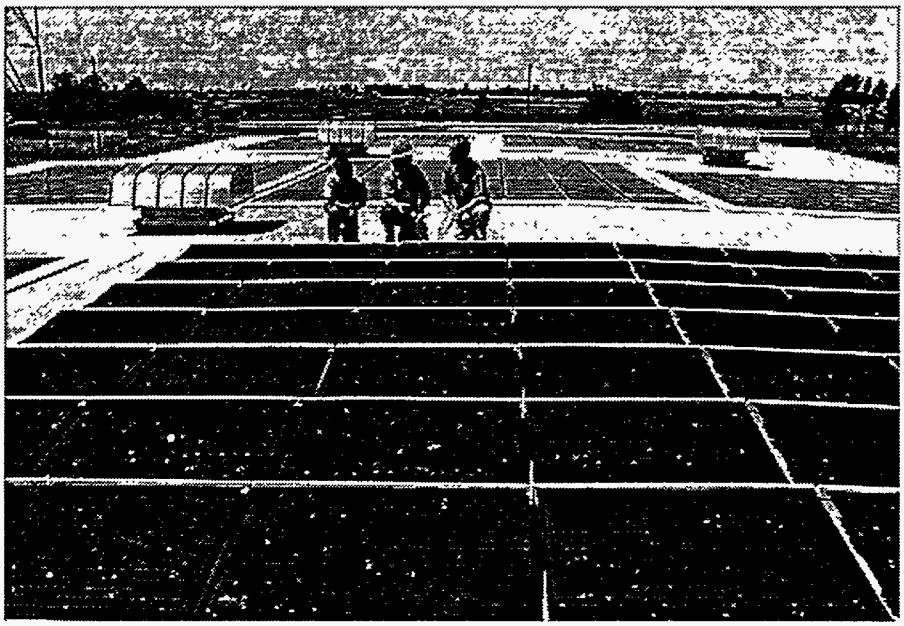
Sys Problems/Resolutions:

- Project was delayed for development of new UPG integrated power processor with tracker controller and DAS system. System operational, DAS expected to come on-line in 1998.
- One tracker fails to track repeatedly. Problem under investigation by UPG.

History of Operation

Total kWh produced: **NO METER READINGS AVAILABLE**

Project: WAPA BIPV 95



System Information

Module Manufacturer:	Solarex
Inverter Manufacturer:	Omnion 2400
Installer:	Western Single Ply / Powerlight
# of Systems:	1
Rating per System:	40kW
Test Rating per System:	36kW
Total # of kW	
Rating	40kW
Test Rating	36kW
Installation:	1996

System Description:

- Flat roof mounted BIPV system on a warehouse
- horizontal fixed angle array facing up
- building integrated foam block mounting structure
- 600 source circuits feed a 6kW Omnion inverter to a 480/12kV transformer
- 3 parallel strings of 14 MSX-120 modules in series make up each source circuit
- Total of 404 MSX-120 Solarex polycrystalline modules

Sys Problems/Resolutions:

- PV Modules supplied by Solarex were 10% below specs. Solarex supplied an equivalent dollar amount of Solarex MX56 and MX64 Modules
- 15% Failure rate with Omnion 2400 systems. The Omnion 2400 inverters received new control boards in 1997.

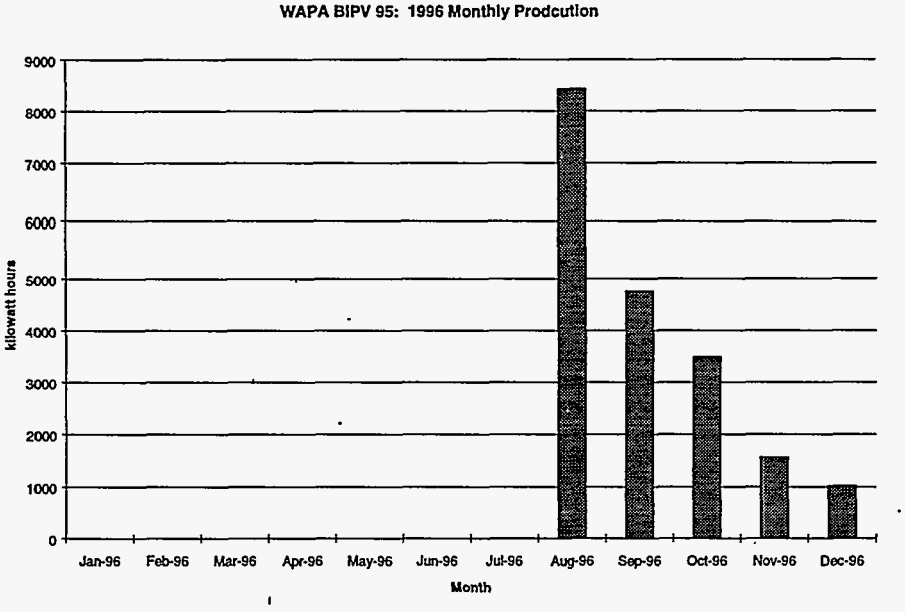
History of Operation

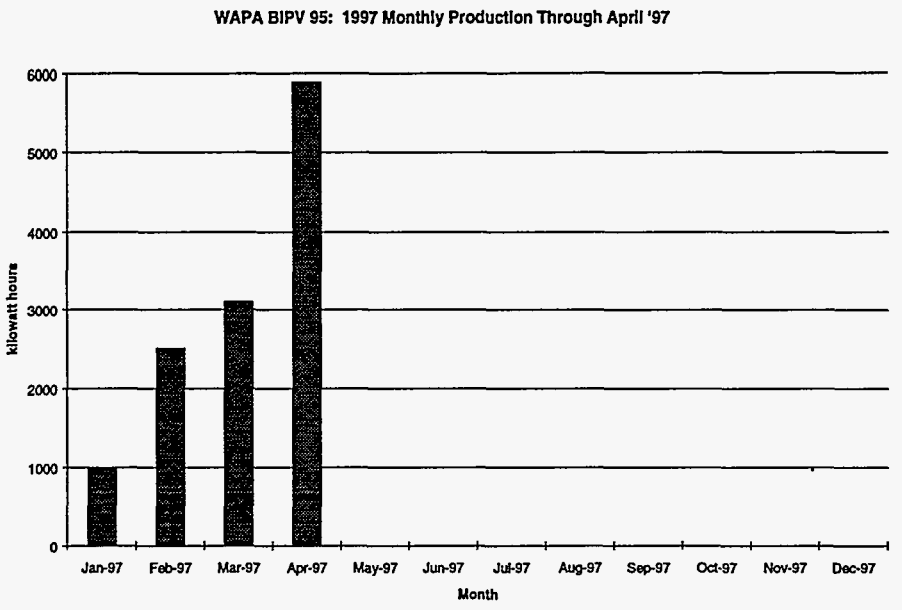
Total kWh produced: 31,689 **(start up - April 30, 1997)**

Monthly Cap Factors: Cap Factors are only available for production in 1995.

Monthly Energy Production (kWh):

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'96								8422	4747	3478	1551	1016
'97	985	2503	3097	5890								




WAPA BIPV 95: 1997 Monthly Production Through April '97
6000
5000
4000
3000
2000
1000
0
kilowatt hours
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
Month

Potential Markets Opportunities

The Roof-top Resource: In metropolitan areas, hundreds of thousands of square acres of residential and commercial roof area, parking lots and transmission corridors are setting unused in the sun. As Skip Fralick of San Diego Gas & Electric Company pointed out, "This rooftop area is the equivalent of "free land" for photovoltaic generation: it needs no development, environmental impact statements, or extensions of transmission lines." In Sacramento alone, these south to west oriented roofs, parking lots and transmission corridors represents the potential of hundreds of megawatts of photovoltaic resource.

Power plant siting is normally a troublesome, time consuming and expensive exercise, especially in a suburban or urban area. However, over the past four years, SMUD has sited over 400 PV power plants all across Sacramento with little trouble or expense. Indeed, hundreds of customers are paying extra on their utility bill to host a SMUD PV power plant on their roof. This ease of siting combined with the environmental, modular and distributed benefits of PV add substantially to the value PV brings to the utility's energy mix.

A Utility Perspective, PV Commercialization: There is a critical need to accelerate and complete commercialization of PVs to meet our needs for grid-connected applications for beyond the year 2000. Without a sustained, collaborative effort we cannot assume that PVs will be ready to serve the utility market when we will need it. Our actions today are our investments for tomorrow.

There are three central concepts necessary to achieve the production levels and cost reductions required for the accelerated commercialization of photovoltaics for utility systems:

- Sustained Orderly Development (SOD)
- Commercialization path life-cycle costing
- Proactive leadership to stimulate early adoption

Sustained Orderly Development (SOD): The solar industry needs reliable, growing and long-term domestic market volume to fully develop and to accelerate the long-term cost reductions required for full commercialization. Current "cost-effective" utility markets have not provided sufficient market volume to accelerate commercialization. Demonstration and R&D projects alone do not accelerate the commercialization of new technologies. In fact, large, one-time purchases tend to dry up supply (and thereby increase price) without stimulating the increase in production capacity necessary for manufacturing cost reductions. Furthermore, manufacturers can not rely upon subsidies, mandated purchases, or set-asides that are short-term or unreliable in making investment decisions.

SMUD has embarked on a path of continued PV procurements with the expectation that PV prices will decline as long as SMUD, with DOE and other utilities and energy providers, provide a sustained commitment to purchase PV systems in sufficient quantities. This commercialization strategy has been referred to as Sustained, Orderly Development (SOD). A combination of

aggressive price reductions and commitments for substantial, growing, and sustained capacity acquisition is required for full commercialization of these technologies. Sustained orderly development and economies of volume for solar electric systems are indeed resulting in the rapid development of a mature, cost-competitive solar industry.

Commercialization Path Life-Cycle Costing: Commercialization path life-cycle costing, and not just "project" life-cycling costing, needs to be used. It is important to analyze total expenditures and total acquired capacity over the entire commercialization path. Higher costs for the first megawatt of a multi-megawatt, multi-year purchase can be a good investment if they contribute to accelerating the trend towards lower costs and higher performance for the following megawatts. When solar investments are selected carefully and in collaboration with other stakeholders in renewable energy development, they can be among the wisest and, ultimately, the lowest risk, long term investment that can be made, despite their higher initial capital costs.

Proactive Leadership to Stimulate Early Adoption: Sustained orderly development and accelerated commercialization will not occur early relying just on natural market forces nor by demonstration projects and watching the cost curve. Utilities and other potential bulk purchasers must commit to an early and sustained series of substantial buys to permit the industry to invest in expanded production and automation. The utility market needs to foster accelerated commercialization with multi-year commitments for substantial and continuing, multi-megawatt per year purchases.

While these early increments of PV may not be cost effective on their own, they have started a cost effective process. Support by the other stakeholders in the process, especially by other utilities, the regulators and a reliable DOE shared risk is required on a sustained, multi-year basis to close the cost-value gap and make the process work. This support, can not be on a year-to-year, stop and go basis. It must be a sustained, multi-year commitment. The utility community has taken the responsibility to get this process underway and to work with regulators, customers and other stakeholders to make it successful. The National Utility PV Group (UPVG, now about 80 utility members) has implemented Project TEAM-UP and provide the initial part of a sustained, orderly development process. A target of 50 MW of utility PV purchases over a four year period has been adopted. Under this program DOE is providing about 30% of the estimated $513 million program. As Andrew Vesey, Chairman of the UPVG Board of Directors and Vice President of Niagara Mohawk Power Corporation stated:

> *While TEAM-UP's partners may greatly help to underwrite today's "cost gap", only the federal government can close it. Critically, this federal support must also be sustained. Funding assurance is essential for gaining market and supplier commitments, gearing up and implementing the program, verifying the march down the cost curve, and establishing the federal government as a reliable partner throughout the entire commercialization process.*

The successful, accelerated commercialization of utility PV applications will need to be a collaborative effort of many participants. Utilities, as well as State and Federal agencies and other stakeholders must join together. If manufacturers do not continue to respond with aggressive

forward pricing, if utilities do not implement substantial, sustained purchases, if DOE does not provide a reliable and predictable multi-year costshare absorbing a part of the early risk and if other stakeholders do not proactively support the commercialization process, this process will not succeed.

Projects Costs

SMUD PV Program Cost Improvements: The SMUD PV Program systems have shown substantial cost improvements each year. This is true both for the turn-key contract costs as well as for the costs incurred by the utility to develop, procure, administer, and perform the utility side of the systems installation and integration into the grid, as can be seen in the following table for the residential systems. These trends are continuing as can be seen from the preliminary analysis of the bids in response to the SMUD Request for Proposals for Renewables (RFR) to provide up to 10 MW of PV for 1998 through 2002. Leading to system costs below $3/W in 2002 positions PV to be a cost-competitive option for the retail customer.

SMUD PV PIONEER SYSTEM COSTS
1993 - 1996 ACTUAL SMUD PV COST IMPROVEMENT
1998/2002 SMUD RFR BID COST ESTIMATES

YEAR	Turn-Key Cost	SMUD Add Cost	Total Cost	Cost Based on	30 yr ¢/kWh
1993	$7.70/W	$1.08/W	$ 8.78/W	Actual	23¢
1994	$6.23/W	$0.90/W	$ 7.13/W	Actual	20¢
1995	$5.98/W	$0.89/W	$ 6.87/W	Actual	18¢
1996	$5.36/W	$0.85/W	$ 6.21/W	Actual	17¢
1998	<$4.25/W	<$0.75/W	<$ 5.00/W	RFR Bid	
2002	<$2.55/W	<$0.45/W	<$ 3.00/W	RFR Bid	

System and Customer Impacts

Customer Attitudes and Response to PV Green Pricing: It is up to local communities, counties, states, utilities and the public at-large to take the lead in demanding and providing the extensive use of solar energy. A 1993 market survey showed that the people of Sacramento are interested in helping to lead the way to a cleaner, sustainable future. The survey results demonstrated the willingness of SMUD customers to support "green pricing" programs for PV.

- Willing to pay a premium price (15%) for PV generated electricity from their rooftops: 26% of the general, and 57% of the "green" population .

- Willing to pay a premium (15%) with rate stabilization of the PV portion: 49% of the general, and 77% "green" population.

- Willing to participate in a general "green pricing" program of 1 to 10% of the utility bill to support a "Clean Energy" program (District wide): 70% of the general, and 88% "green" population.

The customer response to the PV Pioneer Program has greatly exceeded expectations with about 500 to 1000 customers volunteering each year for the approximately 100 PV Pioneer systems available each year. Of those volunteering, about two-thirds pass the pre-qualifying screen and agree to pay the PV Green Fee premium. With the current restrictive roof requirements, qualifying rooftops have been a much greater constraint to volunteers than the "green fee". A 1997 SMUD survey confirmed this public support with over 24% of the general public willing to pay more on their utility bill for PV, 14% willing to pay more than $10/mo and 8% more than $20/mo.

Lessons Learned from the Project

1. Customers want solar. They expect energy suppliers and government to find ways to provide solar such that it is both affordable (does not have to be lower cost but at least able to be afforded) and low hassle.

2. Sustained Orderly Development works as a commercialization strategy for grid-connected PV and is a very effective lever. PV works and works well. This is especially true when a large number of like systems are done at a time and a utility gains valuable experience on the learning curve. Sandia studied the performance of 100 of the PV Pioneer systems during the period 8/96 through 7/97 and found an availability factor of 96% typical. Reliability increases with high volume. (see chart below)

3. PV modules are very reliable, though a better job needs to be done on rating modules (as well as systems).

4. Residential and neighborhood PV systems can be adequately monitored with a standard utility revenue meters that are read once a month with the service revenue meters. This presents a one time cost of less than $100 instead of the $3000+ cost of a DAS with monthly phone line costs.

5. Roof integrated PV systems are clearly desirable and are likely the most cost effective deployment of PV systems in the future.

6. A large PV program installing a hundred or more PV systems takes nearly the same amount of staff time as a few demonstration projects. Thus the administration costs per installed watt is greatly reduced for a large PV Program as well as improving performance and reliability.

7. The grid-protection provided by modern, line-synchronous inverters is both adequate and reliable.

8. Inverters continue to be the source of nearly all of the problems with PV systems. Inverters have improved considerably but remain the weak link. "Nuisance trips" are the biggest problem where the inverters had to be reset because the protection circuitry was too sensitive to normal utility voltage fluctuations. Automatic resetting the inverter and instructing the homeowners on how to reset the units has reduced the number of service calls. Inverters that have been deployed for a number of years in many installations have a much higher reliability because the bugs in the design have been worked out by the manufacturer. New inverter designs always have problems. Longer inverter burn in time with more rigorous factory testing could save much field repair time. A minimum 5 year warranty with manufacturer paying for freight should be requested. A manufacturer willing to service the inverters on site is often provided at no cost even though the warranty does not provide this level of support. Being a large important customer has helped with service support. Local suppliers are more willing to provide on site service. Service trips by inverter manufacturers can be costly.

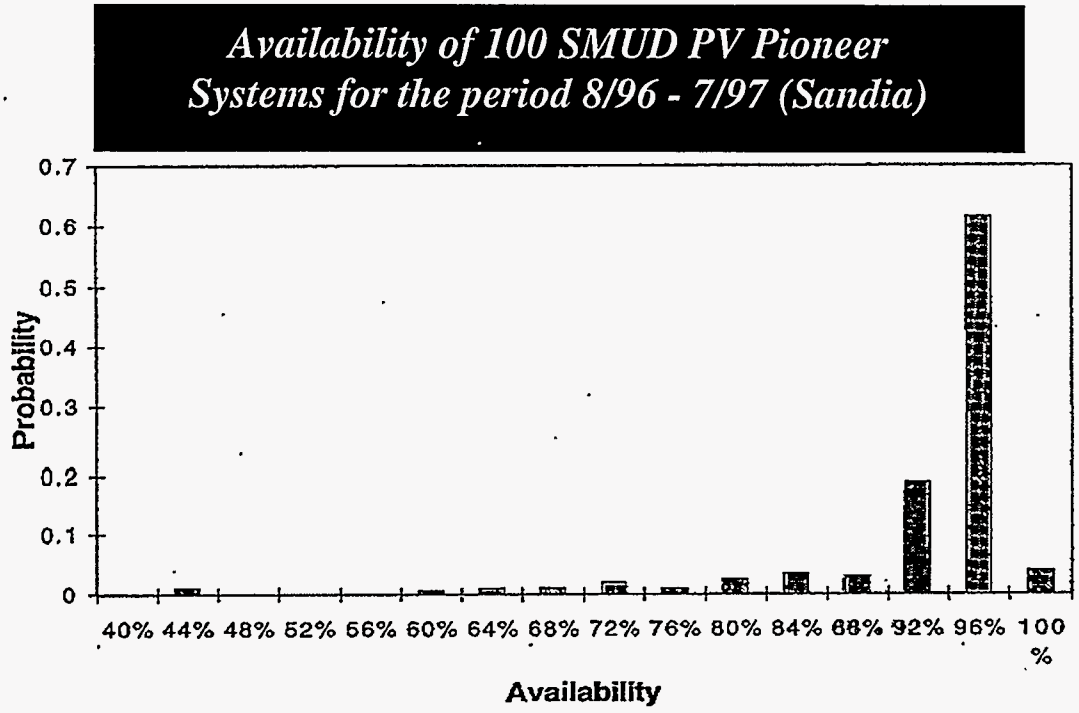
9. The use of multiple small replicated inverters improves system reliability over a system with one custom made large inverter. Spare small inverters for maintenance purposes are more easily cost justified than repair parts for one large inverter.

10. A fully trained and not overworked technician improves PV system reliability. One full time technician for every 500 to 1000 dispersed PV systems is needed until inverters can be more reliable..

11. Active clock driven single axis tracking designs are very reliable and are economically justified over fixed systems and are 8 to 12% more efficient than ground mounted PV systems. A tracking design for PV systems with lower efficient modules must be evaluated because of their higher structure cost per watt.

12. Using imbedded wooden poles instead of steel with concrete foundations for PV system supports has worked very well. Metal to metal bearings on torque tube supports has produced no problems and is expected to last 30+ years.

13. Standardized factory module ratings that give predictable PV system ratings need improvement. The current STC flash test factory ratings vary too much from manufacturer to manufacturer and does not address any initial PV module degradation. A standardized PV module PTC rating after one year of operation would be a great improvement.



Conclusion and Recommendations

- Customers want solar and they expect energy suppliers and government to find ways to provide solar such that it is both affordable (does not have to be lower cost but at least able to be afforded) and low hassle.

- Sustained Orderly Development works as a commercialization strategy for grid-connected PV and is a very effective lever. PV works and works well. This is especially true when a large number of like systems are done at a time and you get well up on the learning curve. Sandia studied the performance of 100 of the PV Pioneer systems during the period 8/96 through 7/97 and found an availability factor of 96% typical. Reliability increases with high volume.

- PV systems work and they work very well. PV system reliability goes up as volume of installations goes up. PV modules are very reliable, though a better job needs to be done on rating modules (as well as systems). The grid-protection provided by modern, line-synchronous inverters is both adequate and reliable. Inverters continue to be the source of nearly all of the problems with PV systems. Inverters have improved considerably but remain the weak link. "Nuisance trips" are the biggest problem.

- Residential and neighborhood PV systems can be adequately monitored with a standard utility revenue meters that are read once a month with the service revenue meters. This presents a one time cost of less than $100 instead of the $3000+ cost of a DAS with monthly phone line costs.

- Roof integrated PV systems are clearly desirable and are likely the most cost effective deployment of PV systems in the future.
- A large PV program installing a hundred or more PV systems takes nearly the same amount of staff time, effort and overhead as just doing a few demonstration projects. Thus the administration costs per installed watt is greatly reduced for a large PV Program.

Next Steps for Project Team

Since this contract project, SMUD has continued on it sustained, orderly development path for the commercialization and implementation of PV in grid-connected applications. SMUD's distributed PV system now totals 6 MW and SMUD has committed to 10 additional MW of PV between 1998 and 2002. This 10 MW program has executed supply contracts in place with firm performance and price milestones leading to less than $3/W total turn-key project costs in 2002. The 10 MW suppliers are Energy Photovoltaics (EPV) for modules, Trace Engineering for inverters, Utility Power Group (UPG) for BOS and installation, and Atlantis Energy for BIPV Energy Roofs. A major PV Factory is being built in Sacramento as a result of these contracts and is scheduled to begin production by the end of 1998.

SMUD has, since this Pre-cursor contract, been awarded contracts under TEAM-UP Rounds I, II, and III. More than 450 separate PV installations have been completed. SMUD's effort are designed to lead directly to a self-sustaining business opportunity for 2002 and beyond. As a result of these efforts and of the DOE support through this contract and the following TEAM-UP contracts, SMUD has announced its commitment to provide 25,000 solar roofs in support of the goals of the National Million Solar Roofs Initiative and to assist in developing 200,000 in California by 2010.