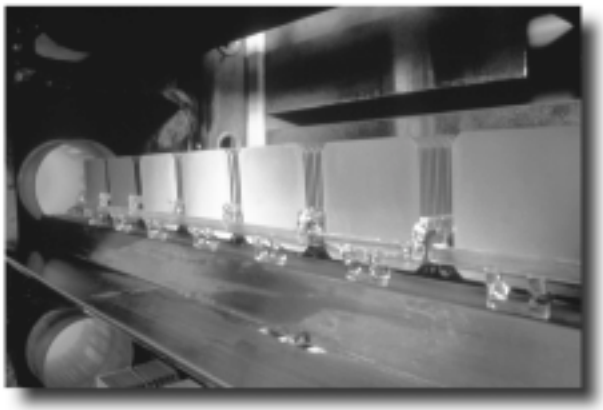

# Photovoltaic Energy Program Contract Summary

## Fiscal Year 1998

U.S. Department of Energy

## MESSAGE FROM THE DIRECTOR

Our mission is to make photovoltaics (PV) a significant and vital part of this country's domestic economy in the years ahead, both as an industry and an energy resource. More than two decades of research and development, in partnership with universities and industry, has advanced PV from a laboratory novelty to today's vital U.S. industry. In 1998, the U.S. photovoltaic industry grew 16%, shipping some 59 megawatts in PV products. The average growth in sales over the past five years has been nearly 22%.

The partnership between the federal PV Program, universities, and industry has been and continues to be the foundation of our success. Direct research as well as management of the bulk of our industry and university subcontract research are provided by two lead laboratories in the National Center for Photovoltaics—the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL). Brookhaven National Laboratory spearheads the efforts in environmental, safety, and health research. The Golden Field Office and the DOE Support Offices in Boston and Albuquerque have also contributed in managing and overseeing subcontracted industry and university research. Every one of these organizations deserves special recognition for its role in managing and conducting the research summarized in this publication, and for making the PV Program one of the most successful research efforts in the U.S. Department of Energy.

This Contract Summary documents some 200 research projects, including more than 70 performed by universities and more than 100 performed by our industry partners. Each individual effort represents another step toward improving PV manufacturing, performance, cost, and applications, and another step toward accomplishing our overall mission.

One change in our administrative process from previous years was that researchers were required to spend their funds before the end of the fiscal year. This special requirement was suitably met, with 97% of the funds spent before the end of fiscal year 1998.

Of the total 1998 PV Program budget of $62.1 million ($66.5 million, with a general reduction of $4.4 million), the industry and university research efforts received $34.6 million, or 56%. And of this amount, about 89% was for contractors selected on a competitive basis. Much of the funding was matched by industry. The result has been steady progress toward our technical, performance, and economic milestones. The partnership that we have forged between industry, universities, and DOE represents a winning strategy—one that we will continue to rely on to maintain U.S. leadership in PV technology in the years ahead.

James E. Rannels, Director
Office of Photovoltaic and Wind Technologies
U.S. Department of Energy
Washington, D.C.

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# INTRODUCTION

The National Photovoltaic Program supports efforts to make photovoltaics (PV) an important part of our economy through three main program elements: Research and Development, Technology Development, and System Engineering and Applications. The research activities are carried out in a coordinated manner by researchers from the national laboratories, industry, and universities. This overview describes the entire scope of PV Program activities. Detailed project descriptions are then provided for subcontracted research activities with industry and universities.

- **Research and Development** activities generate new ideas, test the latest scientific theories, and push the limits of PV efficiencies in laboratory and prototype materials and devices. Other activities define environmental, health, and safety issues for facilities engaged in manufacturing PV products and for organizations engaged in PV research and development. PV Research and Development includes the following areas:

  Fundamental and Advanced Concepts and Research Support
    Fundamental and Exploratory Research
    High-Efficiency Concepts and Concentrators
    Crystalline Silicon
    Measurements and Characterization
    Environmental, Health, and Safety
  Thin Film Technologies Project

- **Technology Development** activities apply laboratory innovations to products to improve PV technology and the manufacturing techniques used to produce PV systems for the market. Technology Development includes the following areas:

  PV Manufacturing Technology (PVMaT)
  Photovoltaic System Components Performance and Reliability
    Module Performance and Reliability
    Balance-of-Systems Components Development

- **Systems Engineering and Applications** activities help to improve PV systems and validate the improvements through tests, measurements, and deployment of prototypes. In addition, research on applications helps to validate sales, maintenance, and financing mechanisms worldwide. System Engineering and Applications includes the following areas:

  Photovoltaic System Performance and Engineering
    Systems Performance and Engineering
    Solar Resource Characterization
    Photovoltaics for Utility-Scale Applications (PVUSA)
  PV Markets and Applications Development
    Domestic PV Market Development
    International Market and Applications Development
    Photovoltaics for Buildings
    DOE Field and Regional Support Office Projects

The overall PV Program is a balanced effort of research, manufacturing development, and market development. All activities within the Program are planned and carried out in close collaboration and partnership with the U.S. PV industry. Critical to the success of this strategy is the PV Program's push to reduce the cost of electricity generated by photovoltaics. The program is tackling this goal in three

primary ways: by making devices more efficient, by making PV systems less expensive, and by validating the technology through measurements, tests, and prototypes.

# RESEARCH AND DEVELOPMENT

## Fundamental and Exploratory Research

Research activities generate new ideas, test the latest scientific theories, and push the limits of PV efficiencies in laboratory and prototype materials and devices. One of the principal goals is to support universities as they pursue long-term, fundamental, PV research and development.

The PV Program's fundamental research task areas are to:

- Create the infrastructure of basic material understanding and scientific underpinning of II-VI-based thin-film PV materials.
- Establish quantitative determination of the electric fields at CdTe/CdS solar cell heterojunctions and perform a microprobe study of the effects of chemical passivation on grain-boundary recombination processes in polycrystalline CdTe solar cells.
- Develop very low-cost, durable, and efficient (>10%) photochemical solar cells based on the dye-sensitization of nanocrystalline films of titanium dioxide.
- Explore new ideas in photovoltaics for film deposition and device optimization.
- Support the development of future-generation PV technologies capable of achieving the long-term goals of the DOE PV Program; support undergraduate students at Historically Black Colleges and Universities to encourage them to explore careers in PV; and, facilitate the interaction between subcontractors, external research groups, and in-house research activities to integrate and leverage related projects.
- Develop and maintain state-of-the-art semiconductor device processing techniques.
- Support the acquisition of critical research equipment at universities involved in PV research under the PV Program.

The PV Program is also supported in the fundamental research area by DOE's Office of Energy Research, which funds a number of PV-related contracts to universities. Information on this research can be obtained from Dr. Satyen Deb at NREL.

## High-Efficiency Concepts and Concentrators

High-efficiency, III-V solar cells have been made with efficiencies of 29.5% under AM1.5 Global and 30.2% at 150 X under AM1.5 Direct. Specifically, these cells are monolithic, two-terminal gallium indium phosphide (GaInP) and gallium arsenide (GaAs) devices. The project has two primary parts: (1) pushing the efficiencies to >35%, and (2) working with industry, including the GaInP/GaAs cell industry and the larger concentrator industry. This project is the only one in the PV Program that has a possibility of reaching cell efficiencies of 40%.

The project has four main objectives:

- As a long-term objective, establish III-Vs as a competitive terrestrial PV technology by developing III-V photovoltaic technologies, advancing related science and engineering, coordinating the allied efforts with our partners, and facilitating commercialization.
- Develop III-V concentrator cells and support the mid-term transition of III-V concentrator cell technology to industry for future U.S. utility market needs.
- Reduce the cost of the devices to address lower-concentration systems and, ultimately, to achieve flat-plate costs.

- Work with the concentrator industry to identify the needs of the industry and appropriate ways that these needs can be addressed.

## Crystalline Silicon

The Crystalline-Silicon Research and Development Project conducts research in crystalline-silicon (c-Si) PV technology. The project is jointly managed by NREL and SNL, with emphasis on crystal growth and material processing at NREL and on device processing and development at SNL. The program contains a balance of basic and applied research that is performed in the national laboratories and in universities.

The goal of this project is to accelerate the development of crystalline PV devices and to enhance the U.S. position in crystalline PV technology. The goal is accomplished through the following objectives:

- Develop innovative methods for the growth of next-generation c-Si that have the potential to improve the throughput, lower the energy consumption, and reduce the cost of future c-Si manufacturing, and perform materials characterization and PV cell diagnostics to evaluate these methods.
- Improve the fundamental understanding of silicon impurities and defects through growth of controlled samples, characterization of impurity/defect effects, diagnostic solar cell analysis, and passivation and gettering studies, so that detrimental effects on PV performance can be ameliorated.
- Develop new processes and device structures to improve the performance and/or reduce the cost of c-Si solar cells using commercial c-Si materials.
- Provide technical assistance in device, process, and material characterization.
- Coordinate national laboratory, university, and industry c-Si PV research, and non-PV c-Si R&D programs, through hosting a workshop on defects and impurities in c-Si processing and through operation of a Crystalline-Silicon Research Cooperative.

The Crystalline Silicon Project is being conducted in three tasks:

*Innovative Methods for Next-Generation c-Si Materials Growth*—emphasizes research on innovative silicon crystal-growth methods that will complement work in industry by examining next-generation technologies. These new methods must have the potential to be superior to current c-Si growth methods, which means improvements in throughput, energy cost, materials cost, and conversion efficiency compared to existing approaches.

*Improvement of the Fundamental Understanding of Silicon Impurities and Defects*— seeks to gain an understanding that will help to ameliorate detrimental effects on PV performance of low-cost c-Si silicon. This understanding will be achieved through growth of controlled samples, characterization of impurity/defect effects, diagnostic solar cell analysis, and passivation and gettering studies. This is an important objective with high industry relevance, because the concentration of defects and impurities are frequently increased by the use of lower-cost Si feedstock and c-Si growth methods.

*Device and Process Development*—develops new processes and device structures with a goal of improving commercial PV module performance (cost, efficiency, and reliability). This task emphasizes research activities with near-term impact that are identified collaboratively with major c-Si manufacturers.

## Measurements and Characterization

This project supports the PV Program through test, measurement, characterization, and user-facilities support and research. The client base includes national laboratory R&D, PV Program-supported contractors, and the U.S. photovoltaics industry. As part of this effort, this project maintains a center of excellence for the DOE PV Program with extensive test and measurement facilities and laboratories,

recognized for capabilities and expertise to provide support and research in standardized cell and module performance, electro-optical characterization, analytical microscopy, and surface analysis.

The goals of this project are to assist the advancement of the DOE PV Program though collaborative and support characterization, technical assistance, and the development of new and special techniques to assist research and industry partners with technology development. A primary goal for this fiscal year is to improve responsiveness to clients' needs. Specific objectives include the following:

- Provide technical leadership in the standard evaluation of solar cells and modules, documenting and developing procedures, and leading and supporting the NCPV and the PV community in the performance evaluation of devices.
- Assist R&D and industry efforts in evaluating the electro-optical characterization of materials and components, using state-of-the-art optical, electrical, spectroscopic, and routine measurement methods.
- Support the NCPV and PV efforts with compositional, structural, and physical evaluation of materials and device interfaces using analytical microscopy techniques, spanning the micron through the atomic spatial-resolution scales.
- Conduct surface analysis measurements and characterization to ascertain chemical and compositional information leading to the improvement of device performance and operational lifetime.
- Work with universities and industry to develop new measurement and characterization techniques in response to the needs of the photovoltaics community, emphasizing the development of specific manufacturing-environment techniques to help the U.S. PV industry.
- Facilitate collaboration and information exchange and dissemination through topical meetings, workshops and reviews, reports and publications, and other communications.

## Environmental, Health, and Safety

Brookhaven National Laboratory assists the PV industry by identifying and characterizing potential environmental, health, and safety (EH&S) hazards and by identifying control strategies for new materials, processes, or applications before large-scale commercialization occurs. The PV Program also undertakes special studies related to health and safety in PV laboratories and manufacturing facilities.

The overall objectives of the project at Brookhaven National Laboratory are to:

- Examine potential EH&S barriers associated with new photovoltaic material, processing and application options.
- Identify hazard control strategies for identified barriers.
- Transfer data developed during these research efforts to the photovoltaic community.
- Provide direct support to DOE Headquarters, NREL, and SNL to ensure that their facilities and the facilities of their contractors are operated in an environmentally responsible manner.

## Thin Film PV Technologies Project

Thin-film PV technologies are regarded as having the potential to meet ambitious cost and performance goals consistent with DOE's long-term PV goals. The Thin Film PV Technologies Project is designed to accelerate progress toward these goals. It includes work in copper indium diselenide (CIS), cadmium telluride (CdTe), amorphous silicon (a-Si), and new ideas such as film silicon and new materials and depositions. The objectives of the Thin Film Project are to:

- Support the near-term transition to first-time manufacturing and scale-up of thin-film a-Si, CIS, and CdTe, and of film Si.
- Build a technology base on which these advanced PV technologies can successfully improve manufacturing and can continue to progress in terms of performance, reliability, and reduced cost.
- Continue to sustain innovation to support progress toward ambitious long-term PV cost and performance goals (i.e., 15%-efficient modules at under $\$50/m^2$, capable of lasting 30 years).

A major portion of the project is the Thin Film PV Partnership, which combines the work of National Research Teams with the internal research program at NREL. The national teams, which consist of researchers from U.S. industry, universities, and NREL, work together in shared activities.

*Amorphous Silicon*—The project's work in the area of a-Si seeks to improve stabilized device efficiency by: (1) improving devices that incorporate more-stable, a-Si-based materials deposited by promising new techniques, (2) developing lower-bandgap amorphous materials, (3) understanding light-induced metastability, and (4) understanding how material properties influence device performance.

*Copper Indium Diselenide and Cadmium Telluride*—In CIS, contractors support the exploration of routes for rapidly deploying CIS thin films, especially focusing on developing potentially low-cost manufacturing processes. In CdTe, contractors address critical portions of device structure, including the transparent conducting oxide layer.

# TECHNOLOGY DEVELOPMENT

## PV Manufacturing Technology (PVMaT)

The U.S. Department of Energy initiated the PVMaT project in 1990 to help the domestic PV industry extend its world leadership role. This multi-phased, cost-shared project supports industry to optimize manufacturing and reduce costs, leading to the development of commercial PV modules and systems.

PVMaT Phase 2B addresses process-specific module manufacturing problems of individual module manufacturers. PVMaT Phase 3A's teamed research was designed to address manufacturing issues common to a majority of the PV industry. PVMaT Phases 4A and 5A deal with product-driven manufacturing. Tasks in these phases address the overall goal of improved U.S. market share by meeting market challenges. The thrust is to emphasize the importance of cost reduction, improved efficiency, and manufacturing flexibility and broader market applications for PV systems as a whole.

To accomplish the Phase 4A goals, the solicitation was divided into two parts: (1) 4A1—Product-Driven System and Component Technology, with goals to improve integration efficiency, advance design elegance, and improve component integration and manufacturing; and (2) 4A2—Product-Driven PV Module Manufacturing Technology, with goals to address manufacturing flexibility and module manufacturing cost-reduction for a wider range of PV products.

Phase 5 A, which is a continuation of the 4A approach, places emphasis on specific R&D problems (as defined by the offeror) in manufacturing, and this phase is also divided into two parts: (1) 5A1—PV System and Component Technology, which includes manufacturing improvements directed toward innovative, low-cost, high-return, high-impact PV products; and (2) 5A2—PV Module Manufacturing Technology, which includes, but is not limited to, improvements in module manufacturing processes and the manufacturing, assembly, and integration of systems to build a PV product, as well as the packaging of that product to meet market requirements.

## Module Performance and Reliability

This task seeks to improve and validate the performance, durability, and reliability of PV modules by working in close cooperation and collaboration with the PV industry and with other PV projects. The long-term goals of this task are to help U.S. module manufacturers develop cost-effective products with

30-year service lifetimes and to facilitate the use of these products in commercial PV systems. The more-specific goal is to characterize and improve the performance and reliability of PV modules through applied R&D that is closely coupled with the needs of U.S. manufacturers. For this fiscal year, these goals will be addressed in four interrelated areas of research and development: (1) module/array performance, (2) module reliability/durability, (3) PV-related solar metrology, and (4) module materials research.

### Balance-of-Systems (BOS) Components Development

The PV Program is working to reduce the costs and increase the reliability of the non-module components of the PV system. The BOS Project has three primary objectives. First, improve system reliability through contracts with industry, laboratory evaluations, and technical support. Second, support industry and PVMaT by providing technical services, including a state-of-the-art evaluation laboratory. Third, disseminate information concerning BOS components. In particular, this program will support the Million Solar Roofs Initiative by improving the reliability of a new generation of small inverters (less than 2 kilowatts) and by developing a new anti-islanding standard for U.S. inverters that will be included as a part of IEEE 929.

The BOS program goals are to:

- Advance the reliability of PV electronic components to the levels achieved by more mature products such as televisions and other consumer electronics.
- Reduce life-cycle cost.
- Remove technical barriers to implementing PV.
- Assist component manufacturers in developing more-reliable, cost-effective systems.

## SYSTEMS ENGINEERING AND APPLICATIONS

### Systems Performance and Engineering

Through systems engineering activities, the PV Program works with industry to address design issues, measure the performance of emerging technologies, and develop standards and certification programs. The project will address PV system and subsystem technical issues with solutions that support the *DOE PV Program Five-Year Plan (1996-2000)* goals and accelerate PV commercialization.

To achieve these goals, the following objectives must be met:

- Provide and enhance technical assistance to help the PV industry commercialize PV by using system engineering expertise at SNL, NREL, Florida Solar Energy Center, and Southwest Technology Development Institute to ensure that PV systems meet customer needs and expected design performance.
- Validate the performance, reliability, and life-cycle cost of fielded components and systems and coordinate the integration of new hardware and designs into an expanded range of applications.
- Develop system performance characterization standardized measurements and test procedures and verify PV system and subsystem development by conducting baseline performance testing, evaluation, and comparative analysis.
- Develop and document engineering best practices and technical guidelines for standardized system and subsystem design packages, interface criteria, and test procedures.
- Facilitate and enhance the development of domestic (IEEE, ASTM, UL) and international (IEC) consensus standards and codes (NEC), and support domestic (PowerMark, UL) and international (PVGAP) certification testing programs.
- Conduct information exchange through topical meetings, forums, and workshops.

## Solar Resource Characterization

Characterizing renewable energy resources helps identify renewable energy markets, supports the efficient design of PV systems, and reduces risk and increases investor confidence in deploying renewable energy projects. Resource characterization provides the solar industry with the information necessary to perform analyses of technology performance for all types of applications. This task involves three subtasks: (1) acquiring high-quality solar data, including the development and implementation of measurement systems as part of monitoring programs, (2) developing enhanced assessment methods that allow simulation of data where no actual measurements exist, and (3) disseminating resource information (such as maps, data sets, and solar resource products) using mechanisms such as the World Wide Web.

The overriding goal is to develop and disseminate key information on solar energy resources to the U.S. industry and to energy planners in order to facilitate and accelerate the deployment of their technologies domestically and worldwide. To achieve this goal, the following objectives must be met:

- Develop accurate data bases and maintain reliable measurement activities with defined data quality.
- Develop and validate procedures for characterizing the solar resource, even in the absence of adequate measured data.
- Perform technology- and region-specific resource characterizations accurately, quickly, and reliably.
- Provide a centralized, interactive source of quality-assessed non-proprietary resource data and information.

## Photovoltaics for Utility-Scale Applications (PVUSA)

Photovoltaics for Utility-Scale Applications is a national, public-private partnership that is assessing and demonstrating the viability of utility-scale PV electric generation systems and recent developments in PV technology. The objective of this project is to continue safe and reliable operation of PV systems at PVUSA sites, while disseminating data relevant to the use of PV-generated energy by electric utilities.

## Domestic PV Market Development

This project supports the analytical, applications, and market development activities of the DOE PV Program. As we support both DOE Headquarters in Washington, D.C., and the DOE Golden Field Office in Colorado, we provide a focal point for DOE activities through project development, subcontract management, and technical assistance.

The main goal and objective of this project are to accelerate the acceptance of PV into existing and new domestic markets through education, training, technical facilitation and support, analysis and market valuation, deployment facilitation, support of regulatory and policy development, and support of various stakeholder groups at state and local levels, such as consumer groups, utilities, PV industry, and the deployment industry (builders and developers).

## International Market and Applications Development

This project provides technical assistance to DOE, other government agencies, the renewable energy industry, foreign partners, and financing and development agencies. The purpose is to expand and promote PV systems so as to support sustainable economic development throughout the developing world. About 70% of PV products shipped are destined toward economically sustainable overseas markets. In the mid-term, the realities of the international market will continue to dominate PV sales and market development. As these markets grow, so will international competition. This project helps assure continued attention within key countries to PV rural electrification opportunities and engagement of U.S. industry interests in this expanding opportunity.

The primary goal is to maintain an active international PV program at minimal cost by continuing to assist on-going bilateral negotiations and by building on previous DOE investments. We also seek to leverage non-DOE funds for continued pilot-project development and deployment.

### Photovoltaics for Buildings

In partnership with industry, this project fosters the widespread acceptance of PV-integrated buildings by overcoming technical and commercial barriers and by facilitating the integration of PV into the built environment for the PV and buildings industries and their customers. These goals support the combined missions of the DOE PV and Buildings programs. All activities are conducted in cooperation with current PV/buildings activities at the NCPV and in other federally funded locations such as the Regional Experiment Stations.

The following activities are vital to achieving the goal:

- Facilitate new concept development by participating in and supporting Photovoltaics Building Opportunities in the United States-Two (PV:BONUS-Two) activities, the Million Solar Roofs Initiative, and R&D that will result in new PV/buildings technologies.
- Advance parametric optimization methods (whole-building design approach to optimize building energy efficiency and PV system performance).
- Participate in the codes and standards development process to identify and address issues affecting PV/buildings systems.
- Carry out systems-testing activities to evaluate and improve the linkage of PV systems with building components and systems.
- Facilitate the development of advanced technologies for buildings applications and provide financial and technical support to utility and commercial partners for deploying near-competitive technologies.

### DOE Field and Regional Support Office Projects

The DOE Golden Field Office administers and manages four project areas for the DOE PV Program: Technology Experience to Accelerate Markets in Utility Photovoltaics (TEAM-UP), Utility On-Grid Photovoltaic Applications (Southern California Edison project), Photovoltaics Building Opportunities in the United States (PV:BONUS), and Solar Market Promotion, Technology Transfer, and Educational Services (Solar Energy Industries Association project).

The DOE Boston Regional Support Office manages two grants associated with the Photovoltaic Collaborative Market Project to Accelerate Commercial Technology (PV-COMPACT), which aims to accelerate the commercialization of PV with utilities. These grants are: (1) Photovoltaics for Utilities (PV4U) and Interstate Renewable Energy Council (IREC); and (2) Renewable Energy Technology Analysis (RETA) at Pace University.

## ORGANIZATION OF THIS DOCUMENT

This document—a companion piece to the *Photovoltaic Energy Program Overview, Fiscal Year 1998*—is organized into three main sections corresponding to the PV Program elements: Research and Development, Technology Development, and System Engineering and Applications. Within each of these main sections, the first level of ordering is by the subareas listed at the beginning of this Introduction. Finally, individual subcontracted tasks are ordered alphabetically in each subsection according to the subcontractor's name.

# RESEARCH AND DEVELOPMENT

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-03 | **Contract Period:** 7/31/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Arizona State University<br>PO Box 871603<br>Tempe, AZ 85287-1603 | |
| | **Organization Type**: CU | **Congressional District:** 1 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. L. Hammond<br>**Phone:** 602-727-1221 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $66,932 | **Cost Share Funding:**<br>1998: $13,430 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** Arizona State University purchased an environmental test chamber for damp heat qualification testing of PV modules for U.S. PV manufacturers.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# Silicon-Film™ Substrates Adapted for Low-Cost High-Efficiency GaAs-Based Solar Cells

| **Contract #:** YDC-7-17650-1-1 | **Contract Period:** 10/16/97–10/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | AstroPower, Inc.<br>Solar Park<br>Newark, DE 19716-2000 | |
| | **Organization Type**: IN | **Congressional District:** AL |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>M. Mauk<br>**Phone:** 302-366-0400 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1997: $50,000<br>1998: $0 | **Cost Share Funding:** |

**Project Objective:** The project's objective is to develop a modified Silicon-Film™ material as a large-area, inexpensive substrate for heteroepitaxial growth of high-efficiency GaAs-based solar cells.

**Approach/Background**: The basic approach is to modify the Silicon-Film™ material by the formation of a germanium or germanium-rich $Ge_{1-x}Si_x$ interlayer since very high-efficiency GaAs-based space solar cells use Ge substrates and polycrystalline GaAs solar cells over 20% have been reported for polycrystalline Ge substrates.

**Status/Accomplishments:** AstroPower researchers have grown 1-micron thick Ge epilayer on Silicon-Film™ substrates as well as single-crystal Si substrates to bench mark the process. The Ge films, grown by Closed-Space Vapor Transport, replicate the grain structure of the Silicon-Film™ substrate. The grain dimension of the substrate is approximately 1 mm.

**Planned FY 1999 Milestones:** Provide samples for epitaxial growth of GaAs films.

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** M. Mauk, "Low-Cost Si-Film Substrates for GaAs Solar Cells", *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# Novel Low-Temperature Substrate Technology for Compound Semiconductor Solar Cells on Low-Cost Substrates

| **Contract #:** XAL-4-13357-1 | **Contract Period:** 7/21/94–12/31/97 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | California Institute of Technology<br>1201 E. California Blvd<br>Pasadena, CA 91125 | |
| | **Organization Type**: CU | **Congressional District:** 27 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>H. Atwater<br>**Phone:** 818-395-2197 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $105,740 — 1997: $56,213<br>1995: $74,977 — 1998: $0<br>1996: $28,655 | **Cost Share Funding:** |

**Project Objective:** The project's objective is to develop technology for fabrication of highly crystalline thin-films of germanium on glass for use as a substrate for growth of high-efficiency, thin-film GaAs solar cells.

**Approach/Background**: The basic approach is to grow large-grain Ge films on glass using selective nucleation and solid phase epitaxy. Selective nucleation results from reactions between a patterned array of deposited In dots in amorphous Ge with subsequent solid phase epitaxy processing at temperatures below 450 degrees C. A fundamental problem has been the result that the seed regions have yielded 3 to 5 grains per dot rather than a single grain.

**Status/Accomplishments:** CalTech researchers haven't completed the project's draft final report. They have participated in the High Efficiency PV project within the Center for Synthesis and Processing of Advanced Materials supported by DOE's Basic Energy Sciences Office.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-11 | **Contract Period:** 7/24/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148<br>J. Mazer<br>**Phone:** 202-586-2455<br>**Fax:** 202-586-8148 | California Institute of Technology<br>1200 E. California<br>Pasadena, CA 91125 | |
| | **Organization Type**: CU | **Congressional District:** 27 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>H. Atwater<br>**Phone:** 626-395-2197 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $23,875 | **Cost Share Funding:**<br>1998: $0 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** CalTech replaced the faulty, obsolete scanning electronics by a low-cost computer-based control system for an existing scanning Phi 595 Auger microscope.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# Historically Black Colleges and Universities (HBCU) PV Research Associates Program

| **Contract #:** XAX-5-15021-04 | **Contract Period:** 10/6/95–10/5/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Central State University<br>1400 Brush Row Rd.<br>Wilberforce, OH 45384 | |
| | **Organization Type**: HB | **Congressional District:** 7 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>C. Fuller<br>**Phone:** 937-376-6312 **Fax:** 937-376-6598 | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $22,276 — 1997: $5,639<br>1995: $0 — 1998: $16,916<br>1996: $22,413 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to strengthen the research and education capabilities in photovoltaics; enlarge the scientific and technical knowledge and resource base in PV technology; and attempt to develop through a hands-on approach, highly qualified scientific and engineering personnel to meet current and future national needs in PV.

**Approach/Background:** Central State has leveraged NREL's funding with that from NASA Lewis Research Center and the National Security Agency. The program supported by NASA Lewis (called CARET---"Consortium for the advancement of Renewable Energy Technology") parallels the DOE/NREL program and involves three additional universities. The National Security Agency project is oriented more toward low-density African languages and has renewable energy as a lower-priority part of the project.

**Status/Accomplishments:** Central State University has supported two PV Research Associates: Hakim Evans and Daniel Milo. Their most recent project involved working with representatives from Boone Water Systems (Dayton, Ohio) and Amarillo Pump and Supply Company (Amarillo, Texas) while they participated in constructing a wind/PV hybrid system on the Central State campus. Central's National Security Agency project led to exchange visits with renewable energy workers from World Vision/Senegal and Hakim Evans. Hakim Evans also supported Texas Southern University's REEP project in South Africa.

Central State also created a five-day renewable energy community outreach program for 25 high school students in 1998. The course agenda included water resource management, wind energy, photovoltaics, and hybrid systems.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
Robert D. McConnell, "Results from Undergraduate PV Projects at Seven Historically Black Colleges and Universities," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# Historically Black Colleges and Universities (HBCU) PV Research Associates Program

| **Contract #:** XAX-5-15021-02 | **Contract Period:** 9/21/95–9/20/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Clark Atlanta University<br>James P. Brawley Drive at Fair Street, SW<br>Atlanta, GA 30314 | |
| | **Organization Type**: HB | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>G. Grams<br>**Phone:** 404 880 6907 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $77,838 — 1997: $20,122<br>1995: $57,120 — 1998: $60,365<br>1996: $22,303 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to strengthen the research and education capabilities in photovoltaics; enlarge the scientific and technical knowledge and resource base in PV technology; and attempt to develop through a hands-on approach, highly qualified scientific and engineering personnel to meet current and future national needs in PV.

**Approach/Background**: A Clark Atlanta University strength is its measurements of atmospheric effects on solar radiation resources. Clark Atlanta has had three PV Research Associates.

**Status/Accomplishments:** All three undergraduates are in graduate school with one working on a Master's topic on "High-Performance Simulation of Air Pollution in Atlanta" and another working on a Master's topic on "Characterization of InGaAs Heterostructures.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
Robert D. McConnell, "Results from Undergraduate PV Projects at Seven Historically Black Colleges and Universities," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Fundamental and Exploratory Research

## Historically Black Colleges and Universities (HBCU) PV Research Associates Program

| **Contract #:** XCR-6-15327-01 | **Contract Period:** 10/31/95–10/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Clark Atlanta University<br>James P. Brawley Drive at Fair Street, SW<br>Atlanta, GA 30314 | |
| | **Organization Type**: HB | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>G. Grams<br>**Phone:** 404 880 6907 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $0 — 1997: $0<br>1995: $69,989 — 1998: $0<br>1996: $0 | **Cost Share Funding:** |

**Project Objective:** The project is designed to determine the effects of atmospheric variability on the production of electricity by photovoltaic sources.

**Approach/Background**: A combination of solar radiation measurements, meteorological observations, and computer modeling work was used to carry out an assessment of the efficiency of PV modules under different atmospheric conditions. This has been a joint research project involving Clark Atlanta University with sub-tier subcontractor Vista University in Port Elizabeth, South Africa.

**Status/Accomplishments:** Two identical radiation instruments were installed at the two universities. The instrument is a relatively small, rugged, self-power, rotating shadowband pyranometer manufactured by ascension Technology, In. of Lincoln Center, Massachusetts. Clark Atlanta conducted an evaluation of the overall accuracy of the pyranometer with the help of their mobile lidar system. Vista monitored solar insolation at representative PV sites in South Africa having potential atmospheric pollutant problems from smoke and aerosols. The logistics of this joint project between a U.S. and South African university were time consuming. Nevertheless, the project established an international research relationship between the two groups.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
Robert D. McConnell, "Results from Undergraduate PV Projects at Seven Historically Black Colleges and Universities," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-10 | **Contract Period:** 8/17/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Clemson University<br>300 Brackett Hall, Box 345702<br>Clemson, SC 29634-5702 | |
| | **Organization Type**: CU | **Congressional District:** 3 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. Singh and K. Poole<br>**Phone:** 864-656-0919 and 864-656-5925 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $94,472 | **Cost Share Funding:**<br>1998: $49,794 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** Clemson fabricated a recently invented, direct liquid injection assisted, rapid photothermal processing assisted, chemical vapor deposition system for fabricating thin film silicon solar cells.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-04 | **Contract Period:** 7/17/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Colorado School of Mines<br>1500 Illinois<br>Golden, CO 80401 | |
| | **Organization Type**: CU | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. Marr<br>**Phone:** 303-273-3008 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $83,000 | **Cost Share Funding:**<br>1998: $48,000 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The Colorado School of Mines purchased an atomic force microscope to improve and complement studies of polycrystalline films.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

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| **Contract #:** AAD-8-18669-01 | **Contract Period**: 8/7/98–3/30/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Georgia Tech Research Corporation<br>400 Tenth Street, CRB<br>Atlanta, GA 30332-0420 | |
| | **Organization Type**: CU | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>A. Rohatgi<br>**Phone:** 404-894-7692 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $60,670 | **Cost Share Funding:**<br>1998: $6,730 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** Georgia Tech developed and validated a continuous beltline rapid thermal processing (RTP) machine to produce low-cost high efficiency RTP cells.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# Solar Energy Conversion at Dye-Sensitized Nanostructured Electrodes Fabricated by Sol-Gel Processing

| **Contract #:** XAD-3-12114-4 | **Contract Period:** 7/15/93–4/15/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Johns Hopkins University<br>3400 N. Charles Street<br>Baltimore, MD 21218-2686 | |
| | **Organization Type**: CU | **Congressional District:** 7 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>P. Searson and G. Meyer<br>**Phone:** 410-516-8668 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $50,000 — 1997: $47,820<br>1995: $175,600 — 1998: $0<br>1996: $90,727 | **Cost Share Funding:** |

**Project Objective:** The project's objective is to develop new materials, electrolytes, and molecular sensitizers which increase solar energy conversion efficiency and stability in photoelectrochemical cells based on dye-sensitized $TiO_2$ polycrystalline films.

**Approach/Background**: The approach is to explore sol-gel processing of the electrodes and to synthesize and characterize new molecular dyes. The work includes studies of charge transport and electron injection mechanisms to improve cell performance.

**Status/Accomplishments:** Johns Hopkins researchers completed the project's final report.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** P. Searson and G. Meyer, "Solar Energy Conversion at Dye Sensitized Nanostructured Electrodes Fabricated by Sol-Gel Processing—Final Report," NREL/SR-520-24521, (July 1998)
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# Historically Black Colleges and Universities (HBCU) PV Research Associates Program

| **Contract #:** XAX-5-15021-06 | **Contract Period:** 10/6/95–10/5/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Mississippi Valley State University<br>14000 Highway 82 W<br>Itta Bena, MS 38941-1400 | |
| | **Organization Type**: HB | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>B. Balam<br>**Phone:** 601-254-3377 **Fax:** 601-254-3668 | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $40,000 — 1997: $11,236<br>1995: $0 — 1998: $33,708<br>1996: $42,400 | **Cost Share Funding:** |

**Project Objective:** The objectives for the Mississippi Valley State University (MVSU) program are to (1) familiarize the students with the issues surrounding photovoltaics, (2) educate the students on the primary and auxiliary technologies involved in solar power, (3) develop a solar power research base to accumulate knowledge and perform original research on different aspects of solar power utilization processes, and (4) expose the students to career and business opportunities in photovoltaics.

**Approach/Background:** MVSU has been monitoring solar radiation from the rooftop of their Fielding Wright Science Building since 1985. The data are fed to NREL's central monitoring system. These measurements have also been instrumental in teaching students to predict annual average power generation for various kinds of solar cells and to learn how the angle of solar incidence, type of cloud cover, and other factors affect the solar power signature.

**Status/Accomplishments:** This program started about one year late when a new principal investigator took over. It will end in 1999. MVSU held a symposium on photovoltaics on May 8, 1998, where three faculty members and seven students made presentations. The audience included the entire faculty and interested students from the Department of Natural Sciences and Environmental Health and concluded with a lively discussion among all.

**Planned FY 1999 Milestones:** Complete the program's final year.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
Robert D. McConnell, "Results from Undergraduate PV Projects at Seven Historically Black Colleges and Universities," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-16 | **Contract Period:** 7/29/98–2/28/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | North Carolina State University<br>Lower Level Leazar Hall, Box 7514<br>Raleigh, NC 27695-7514 | |
| | **Organization Type**: CU | **Congressional District:** 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>G. Rozgonyi<br>**Phone:** 919-515-2934 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $100,000 | **Cost Share Funding:**<br>1998: $57,000 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** North Carolina State University acquired a variable temperature laser microwave photoconductance decay apparatus to enhance their materials diagnostic capabilities for making contactless measurements of carrier lifetime in silicon substrates and thin films.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-09 | **Contract Period:** 8/17/98–10/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King **Phone:** 202-586-1693 **Fax:** 202-586-8148<br>J. Mazer **Phone:** 202-586-2455 **Fax:** 202-586-8148 | Pennsylvania State University<br>110 Technology Center<br>University Park, PA 16802 | |
| | **Organization Type**: CU | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>C. R. Wronski<br>**Phone:** 814-865-0930 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $50,245 | **Cost Share Funding:**<br>1998: $27,055 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** Pennsylvania State University developed a real time spectroscopic polarimeter that can perform measurements on actual textured surfaces used in the industrial processes.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# High-Efficiency GaAs Solar Cells on Polycrystalline Ge Substrates

| **Contract #:** YAL-4-13357-3 | **Contract Period:** 8/16/94–12/31/97 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Research Triangle Institute<br>PO Box 12194<br>Research Triangle Park, NC 27709 | |
| | **Organization Type**: NP | **Congressional District:** 12 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. Venkatasubramanian<br>**Phone:** 919-541-6889 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $250,000 — 1997: $214,000<br>1995: $100,000 — 1998: $0<br>1996: $206,000 | **Cost Share Funding:** |

**Project Objective:** The project's objective was to reach 90% of the efficiency levels attained on single crystal substrates for the fabrication of GaAs solar cells on lower cost polycrystalline Ge substrates.

**Approach/Background**: The basic approach is to employ device engineering to mitigate minority carrier recombination at grain boundaries through minority carrier mirrors. Again through device engineering dark currents at the grain boundary minority carrier mirrors are reduced to increase the open circuit voltage.

**Status/Accomplishments:** Research Triangle Institute completed the project's final report. A final efficiency of 21% (not confirmed at NREL) was measured by RTI on a device employing their innovative device engineering concepts.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** R. Venkatasubramanian, "High-Efficiency GaAs Solar Cells on Polycrystalline Ge Substrates----Final Report," NREL/SR-590-24820, (August 1998).
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# Historically Black Colleges and Universities (HBCU) PV Research Associates Program

| **Contract #:** XAX-5-15021-05 | **Contract Period:** 9/28/95–9/28/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Southern University and A&M College<br>PO Box 12596<br>Baton Rouge, LA 70813-0400 | |
| | **Organization Type**: HB | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. Bobba<br>**Phone:** 504-771-2493 **Fax:** 504-771-2324 | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $0 — 1997: $5,163<br>1995: $20,650 — 1998: $15,487<br>1996: $20,650 | **Cost Share Funding:** |

**Project Objective:** This project focuses on training and motivating African-American undergraduate students in future photovoltaic generation technologies, materials research, and education.

**Approach/Background:** Southern University's PV program provided hands-on experience for a total of 10 students in preparing and characterizing semiconductor thin films (amorphous Si, porous Si, doped and undoped CdTe and ZnTe thin films) and solid electrolyte materials including glasses, single crystals, and thin-film samples for fuel cells, Li-ion batteries, and photovoltaic electrochemical solar cells using advanced spectroscopic and electrochemical techniques.

**Status/Accomplishments:** This program ended in 1998. Several of Southern's students graduated and new PV Research Associates entered the program. Several of Southern's undergraduates worked as summer interns at NREL on projects ranging from outdoor testing of PV modules to innovative flywheel energy storage to fundamental studies of CdTe materials and devices.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
Robert D. McConnell, "Results from Undergraduate PV Projects at Seven Historically Black Colleges and Universities," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)
H. Moutinho, B. Mayo, et al, "Induced Recrystallization of CdTe Thin Films Deposited by Close-Spaced Sublimation," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-15 | **Contract Period:** 7/24/98–1/31/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | State University of New York at Buffalo<br>211 UB Commons, 520 Lee Entrance<br>Amherst, NY 14228-2567 | |
| | **Organization Type**: CU | **Congressional District:** 27 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>W. Anderson<br>**Phone:** 716-645-2422, x1215 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $32,935 | **Cost Share Funding:**<br>1998: $19,000 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The State University of New York at Buffalo added photon assistance, provided in-situ diagnostics, and improved the pumping control for their microwave electron cyclotron deposition system.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-06 | **Contract Period:** 7/30/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Syracuse University<br>113 Bowne Hall<br>Syracuse, NY 13244-1200 | |
| | **Organization Type**: CU | **Congressional District:** 25 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>E. Schiff<br>**Phone:** 315-443-3901 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $16,615 | **Cost Share Funding:**<br>1998: $0 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** Syracuse University upgraded their 11-year old facility for photocarrier drift mobility measurements in amorphous silicon solar cells.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# Historically Black Colleges and Universities (HBCU) PV Research Associates Program

| **Contract #:** XAX-5-15021-03 | **Contract Period:** 10/19/95–10/18/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Texas Southern University<br>3100 Cleburne<br>Houston, TX 77004 | |
| | **Organization Type**: HB | **Congressional District:** 18 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J. Hill<br>**Phone:** 713-313-7007 **Fax:** 713-313-1853 | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $22,616 — 1997: $5,654<br>1995: $0 — 1998: $16,962<br>1996: $22,616 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to strengthen the research and education capabilities in photovoltaics; enlarge the scientific and technical knowledge and resource base in PV technology; and attempt to develop through a hands-on approach, highly qualified scientific and engineering personnel to meet current and future national needs in PV.

**Approach/Background**: In January 1997, Texas Southern University (TSU) installed a 4 kilowatt PV system on campus with funding from Houston Lighting and Power and the Electric Power Research Institute. The successful installation and operation of the PV system has been an excellent educational tool for TSU and has provided a testbed and demonstration medium for local groups involved in promoting and testing PV technologies. TSU also created the Renewable Energy and Environmental Protection (REEP) Academy with the following mission statement: "The TSU REEP Academy is a college preparatory program that encourages minority high school students to pursue education and careers in the math, science, engineering, and technology fields by presenting concepts in renewable energy and environmental protection through a combination of technical seminars, college preparatory courses, laboratory activities, field exercises, leadership development seminars, and community service project."

**Status/Accomplishments:** TSU held its third annual REEP Summer Academy from July 12, 1998, through August 1, 1998. Based on the successes of the previous years the program was able to expand its technical sessions, lab experiments, and tours. The program included three major field trips: to South Africa, West Texas A&M's Alternate Energy Institute (Canyon, Texas), and NREL. Over 50 students traveled to NREL while a select group of one dozen traveled to South Africa. TSU's tour to South Africa was done in collaboration with Port Elizabeth Technikon in Port Elizabeth, South Africa. One highlight for the students was the installation of a PV home lighting system for a family in a rural, non-electrified South African village.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
Robert D. McConnell, "Results from Undergraduate PV Projects at Seven Historically Black Colleges and Universities," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# Ultra-Efficient Epitaxial Liftoff Solar Cells Exploiting Optical Confinement in the Wave Limit

| **Contract #:** XAL-4-13357-2 | **Contract Period:** 7/19/94–7/19/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of California at Los Angeles<br>1400 PVUB<br>Los Angeles, CA 90024-1406 | |
| | **Organization Type**: CU | **Congressional District:** 29 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>E. Yablonovitch<br>**Phone:** 310-206-2240 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $166,000 — 1997: $36,000<br>1995: $106,000 — 1998: $80,000<br>1996: $110,000 | **Cost Share Funding:** |

**Project Objective:** The project's initial objective was to explore and develop a high efficiency, low cost, GaAs solar cell. As research progressed, the objective shifted to work on large area manufacturability of crack-free films.

**Approach/Background**: The basic approach is to develop an HF acid vapor epitaxial liftoff technique, demonstrated as a viable option in this project, for separating large area, crack free, thin film solar cell material from a parent substrate.

**Status/Accomplishments:** UCLA researchers are preparing the project's draft final report.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-07 | **Contract Period:** 8/12/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Delaware<br>Newark, DE 19716 | |
| | **Organization Type**: CU | **Congressional District:** AL |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>W. Shafarman<br>**Phone:** 302-831-6215 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $100,000 | **Cost Share Funding:**<br>1998: $37,250 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The University of Delaware's Institute for Energy Conversion purchased a scanning probe microscope to provide critical information needed to correlate material microstructure with PV device properties.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-17 | **Contract Period:** 7/24/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Florida<br>219 Grinter Hall<br>Gainesville, FL 32611 | |
| | **Organization Type**: CU | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>T. Anderson<br>**Phone:** 352-392-0882 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $91,000 | **Cost Share Funding:**<br>1998: $0 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The University of Florida purchased a rebuilt sputter deposition system for Mo and ZnO film deposition for $Cu(In,Ga)Se_2$ solar cells.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

# Fundamental Studies of the Effect of Crystal Defects on $CuInSe_2$ Heterojunction Behavior

| **Contract #:** XAD-3-12114-1 | **Contract Period:** 6/28/93–6/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Illinois at Urbana-Champaign<br>109 Coble Hall<br>Champaign, IL 61820-6242 | |
| | **Organization Type**: CU | **Congressional District:** 15 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>A. Rockett<br>**Phone:** 217-333-0417 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $85,000 — 1997: $0<br>1995: $154,470 — 1998: $0<br>1996: $96,553 | **Cost Share Funding:** |

**Project Objective:** The project's objective is to understand the sample-to-sample variability in CIGS-based solar cells as well as the mechanisms restricting carrier collection at high voltages in CIGS/CdS heterojunctions. These objectives involve determining the relative importance of structural and chemical defects in the materials.

**Approach/Background**: The basic approach is to grow the highest quality CIGS under a variety of conditions and to measure the morphology, microstructure, and properties of the resulting layers.

**Status/Accomplishments:** University of Illinois researchers completed the project's draft final report. It has been reviewed and is in press.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** A. Rockett, "The Electronic Effects of Point Defects on CIGS Devices", *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-13 | **Contract Period:** 7/20/98–10/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Oregon<br>5219 University of Oregon<br>Eugene, OR 97403-5219 | |
| | **Organization Type**: CU | **Congressional District:** 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J. D. Cohen<br>**Phone:** 541-346-4775 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $45,787 | **Cost Share Funding:**<br>1998: $17,929 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The University of Oregon updated and enhanced capacitance spectroscopy instrumentation and a glow discharge growth system for amorphous silicon.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

## Heterojunction Development and Optimization in Thin-Film Compound Semiconductor Cells

| **Contract #:** XAD-3-12114-3 | **Contract Period:** 5/12/93–5/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of South Florida<br>4202 East Fowler Avenue, FAO 126<br>Tampa, FL 33620 | |
| | **Organization Type**: CU | **Congressional District:** 11 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. Morel<br>**Phone:** 813-974-2508 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $110,000 — 1997: $0<br>1995: $97,410 — 1998: $0<br>1996: $203,587 | **Cost Share Funding:** |

**Project Objective:** The project's objective is to advance the understanding of the formation and performance of thin-film compound semiconductor solar cells.

**Approach/Background**: The basic approach is to explore the applicability of Shockley-Read-Hall recombination theory, which works for CdTe devices, to CIGS solar cells.

**Status/Accomplishments:** University of South Florida researchers still haven't completed the project's draft final report.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** No report submitted for last year's *NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** D. Morel, "Interface Mechanisms in CIGS Solar Cells", *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-05 | **Contract Period:** 7/16/98–2/28/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of South Florida<br>4202 E. Fowler Ave., ADM 147<br>Tampa, FL 33620 | |
| | **Organization Type**: CU | **Congressional District:** |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. Morel and C. Ferekides<br>**Phone:** 813-974-2508 and 4818 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $97,913 | **Cost Share Funding:**<br>1998: $0 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The University of South Florida constructed an advanced research system for the in-situ deposition of CdS and CdTe by close-spaced-sublimation on large moving substrates.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| | |
|---|---|
| **Contract** #: AAD-8-18669-12 | **Contract Period:** 7/21/98–2/28/99 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King **Phone:** 202-586-1693 **Fax:** 202-586-8148<br>J. Mazer **Phone:** 202-586-2455 **Fax:** 202-586-8148 | University of South Florida<br>4202 E. Fowler Ave., ADM147<br>Tampa, FL 33620 | |
| | **Organization Type**: CU | **Congressional District:** 11 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>S. Ostapenko<br>**Phone:** 813-974-2031 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $50,000 | **Cost Share Funding:**<br>1998: $0 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The University of South Florida will obtain a defect mapping system for correlation of defects with photoluminesce in silicon wafers.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-08 | **Contract Period:** 7/16/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Toledo<br>2801 West Bancroft<br>Toledo, OH 43606 | |
| | **Organization Type**: CU | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>X. Deng and A. Compann<br>**Phone:** 419-530-4782 and 4787 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $49,225 | **Cost Share Funding:**<br>1998: $49,225 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The University of Toledo acquired a novel hot wire deposition chamber for the deposition of high quality a-SiGe films and an optical absorption spectroscopy system for an improved understanding of the deposition process.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# Electronic Process in Thin Film PV Materials

| **Contract #:** XAD-3-12114-2 | **Contract Period:** 4/12/93–12/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Utah<br>309 Park Building<br>Salt Lake City, UT 84112 | |
| | **Organization Type**: CU | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>P. C. Taylor<br>**Phone:** 801-581-3538 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $223,711 — 1997: $59,999<br>1995: $183,299 — 1998: $0<br>1996: $0 | **Cost Share Funding:** |

**Project Objective:** The project's objectives are to identify a-Si:H metastabilities and to determine if they are intrinsic or extrinsic, to characterize important defects and impurities at cell interfaces, and to measure hydrogen motion in a-Si:H.

**Approach/Background**: Three approaches have been emphasized: a variety of below-gap spectroscopies using a tunable laser system to excite carriers, novel nuclear magnetic resonance techniques to probe local hydrogen motion, and doping of a-Si:H with group IV elements that introduce new metastabilities.

**Status/Accomplishments:** University Utah researchers completed the project's final report. They have also participated in the High Efficiency PV project within the Center for Synthesis and Processing of Advanced Materials supported by DOE's Basic Energy Sciences Office.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** P.C. Taylor, C. Chen, S.L. Chen, K. Gaughan, S.Q. Gu, P. Hari, S. Hershgold, D. Mao, W.D. Ohlsen, T. Su, J.M. Viner, W. Xu, B. Yan, G.A. Williams, "Electronic Processes in Thin-Film PV Materials---Final Report," NREL/SR-520-24840 (July 1998).
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-02 | **Contract Period:** 7/14/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Utah<br>1471 Federal Way<br>Salt Lake City, UT 84102 | |
| | **Organization Type**: CU | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>P. C. Taylor<br>**Phone:** 801-581-8751 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $49,280 | **Cost Share Funding:**<br>1998: $0 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** The University of Utah upgraded their Bruker Electron Spin Resonance Spectrometer that had not been upgraded in the last decade. It is used for probing microscopic properties of paramagnetic defects and impurities in thin-film PV materials.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Fundamental and Exploratory Research

# University PV Research Equipment

| **Contract #:** AAD-8-18669-14 | **Contract Period:** 7/22/98–12/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Washington State University<br>PO Box 643140<br>Pullman, WA 99164-3140 | |
| | **Organization Type**: CU | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>L. Olsen<br>**Phone:** 509-372-7221 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>University Price Participation |
| | **DOE Funding Allocation:**<br>1998: $49,156 | **Cost Share Funding:**<br>1998: $12,000 |

**Project Objective:** The project's objective is to fund the acquisition of critical photovoltaic research and test equipment at universities participating in the DOE PV program to enhance their research capabilities as well as their research results.

**Approach/Background**: Many universities in the PV program have been working with outdated research equipment, sometimes decades old, that has affected both the quality and efficiency of their research. This university received these funds as a result of a competitive solicitation in 1998.

**Status/Accomplishments:** Washington State University added a sputtering system for depositing transparent conducting oxides for CIS-based solar cells.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Crystalline Silicon

# Low Cost Glass and Glass-Ceramics Substrates for Thin Film Silicon Solar Cells

| **Contract #:** XAF-8-17607-06 | **Contract Period:** 2/1/98–12/1/00 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Cornell University<br>Materials Science and Engineering<br>Bard Hall, Room #229<br>Ithica, NY 14853-1501 | |
| | **Organization Type**: CU | **Congressional District:** 26 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. Ast<br>**Phone:** 607-255-4140 **Fax:** 607-255-2365 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1998: $105,000 | **Cost Share Funding:** |

**Project Objective:** The objective of the proposed research is to develop a high-temperature glass substrate suitable for thin film silicon solar cells. The proposed research requires: i) the development of suitable glass-ceramic substrates with coefficients of thermal expansion close to that of Si (36 +/-4 x $10^{-7}$ /°C), and optical transmissions of greater than 90% (measured without an AR coating) and ii) the development of methods to prevent the outmigration of impurities into the Si film.

**Approach/Background:** Deposition of a thin Si film on glass demands that the substrate meet requirements of thermal matching and purity. The typical low-cost glass cannot be used for typical high temperature depositions. The tasks under this area include: methods for silicon film deposition/growth on low-cost substrates suitable for solar cells, identification of the characteristics of low-cost substrates for silicon layer deposition and interface control, cell processing techniques compatible with thin silicon layers on low-cost substrates, novel cell designs and process techniques. In the proposed glass-ceramic effort, the development of suitable glass-ceramics will be handled by Corning *at no cost to* NREL. This subcontract will include following tasks:
Task 1, Development of the substrate material
Task 2, the study of the impurity traffic between the substrate and the barrier layer.
Task 3, the study of the impurity traffic between the deposited Si film and the substrate/barrier system.

**Status/Accomplishments:**

**Planned FY 1999 Milestones:**
- Results of the migration of glass components out of the substrate and *into* the deposited barrier layer. These results will relate to studies involving a series of annealing experiments with secondary ion mass spectroscopy (SIMS) being the major technique
- Characteristics of poly-Si deposited *across* the different types of barrier layers into the ply-Si films,
- Results of the experiments to identify if Na, K or other alkali migrate out from the substrate into the poly-Si film

**Major Reports Published in FY 1998:**
1998 NREL Annual Report

**Major Articles Published in FY 1998:**
8th Workshop on Silicon Solar Cell Materials and Processing

# Investigation of Getting MechanismsIn Crystalline Silicon

| **Contract #:** XAF-7-17607-01 | **Contract Period:** 7/21/97–3/31/00 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Duke University, Box 90300<br>Dept. of Mechanical Engineering & Materials Science<br>Durham, NC 27706-0300 | |
| | **Organization Type**: CU | **Congressional District**: 12 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>T. Tan<br>**Phone:** 919-660-5323 **Fax:** 919-660-8963 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1997: $145,00<br>1998: $30,000 | **Cost Share Funding:** |

**Project Objective:** The objective of the proposed research is to investigate gettering and passivation of defect cluster regions in commercial silicon solar cells.

**Approach/Background:** The research performed to date has identified that impurity gettering and defect passivation can be successfully applied to mitigate the effects of impurities and defects in commercial photovoltaic silicon. The optimization of such processes has resulted in small-area solar cells with efficiencies greater than 18.5% on commercial substrates. However, attainment of high efficiencies in large-area cells is limited by the effects of defect clusters. Hence, further research is needed to understand basic material properties, identify mechanisms that limit large-area performance, and arrive at processes that ameliorate the influence of performance-limiting mechanisms in large-area solar cells. This is to be accomplished by: (a) gaining an understanding of the nature of impurity precipitation and dissolution in regions of defect clusters through modeling, (b) measuring recombination activity of various precipitates, and (c) using this knowledge to design low-cost processes to improve the regions in silicon containing defect clusters.

**Status/Accomplishments:**
Initial calculations were performed to determine time and temperature dependence for dissolution of Fe precipitates.

**Planned FY 1999 Milestones:**
*Modeling of Metal Silicide Precipitate Dissolution During Gettering*: Physical and numerical modeling will be completed to determine the metal silicide dissolution process during gettering by assuming that the process is limited by impurity atom diffusion in the Si matrix without considering the role of the interfacial energy between the precipitate and the Si matrix material.

**Major Reports Published in FY 1998:**
1998 NREL Annual Report

**Major Articles Published in FY 1998:**
Papers published in the Proceedings of the 8th Workshop on Silicon Solar Cell Materials and Processing

# Crystalline Silicon Research Center of Excellence

| **Contract #:** AA-1638 and AO-6162 | **Contract Period:** 6/11/92–6/30/2000 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Georgia Institute of Technology<br>Atlanta, GA 30332-0250- | |
| | **Organization Type**: CU | **Congressional District:** 05 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>A. Rohatgi<br>**Phone**: 404-894-7692 **Fax**: 404-853-9882 | |
| **Technical Monitor:**<br>D. S. Ruby<br>**Phone**: 505-844-0317<br>**Fax**: 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1995: $525,000<br>1996: $500,0000<br>1997: $548,0000<br>1998: $467,0000 | **Cost Share Funding:** |

**Project Objective:** Improve the state of the art in crystalline-silicon solar cells through research on high-efficiency, one-sun, single- and multicrystalline silicon solar cells; improve fundamental understanding of efficiency-limiting defects and mechanisms; develop low-cost manufacturable processes; train future professionals in photovoltaic technology; and transfer new technology to industry through collaborative research.

**Approach/Background:** Conduct collaborative research with students from other universities and industry. Develop high-efficiency float-zone (FZ) and multicrystalline silicon solar cells in order to demonstrate new device concepts. Develop new processes for fabricating solar cells, including Rapid Thermal Processing (RTP). Develop characterization and modeling tools for high efficiency silicon solar cells.

**Status/Accomplishments:** Pioneered Rapid Thermal Processing (RTP) of solar cells, which reduces cell processing time from 16 to 2 hours. Fabricated record high 17.6 percent 4 $cm^2$ fully screen printed RTP cells. Produced record high ~17 percent efficient 4 $cm^2$ cells on monocrystalline silicon by a low-cost manufacturable process using screen printing, beltline diffusion, and PECVD SiN. Fabricated bifacial cells with record high rear illumination efficiency for screen printed bifacial cells. Fabricated record high efficiency 100 m thick 15.4 percent, string ribbon cells and 16 percent EFG sheet Si cell. Successfully maintained and monitored 342kW Georgia Tech PV system.

**FY 1999 Milestones:** Reduce cell processing time to < 2 hours/batch using RTP screen-printed contacts (SPC) while maintaining high efficiency. Fabricate 4 $cm^2$ RTP/PECVD/SPC cells on Cz silicon and multicrystalline silicon with efficiency targets of 18 and 16.5 percent, respectively. Fabricate 10 $cm^2$ RTP/PECVD/SPC cells on Cz silicon and multicrystalline silicon with efficiency targets of 17 and 16 percent, respectively. Fabricate 10 $cm^2$ cells on PV-industry Cz silicon and multicrystalline silicon with efficiency targets of 20 and 17 percent, respectively, using photolithography contact.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Crystalline Silicon

# High Efficiency Solar Cell Fabrication On Commercial Silicon Substrates

| **Contract #:** XAF-8-17607-05 | **Contract Period:** 2/20/98–2/19/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Georgia Institute of Technology<br>School of Electrical & Computer Engineering<br>777 Atlantic Drive<br>Vanleer Bldg.<br>Atlanta, GA 30332 | |
| | **Organization Type**: CU | **Congressional District**: 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>A.Rohatgi<br>**Phone:** 404-894-7692 **Fax:** 404-894-5934 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1998: $140,000 | **Cost Share Funding:** |

**Project Objective:** The objective is to improve the carrier collection efficiency of large-area solar cells. Currently large area cells are limited by high recombination activity in the regions of defect clusters, where gettering and passivation has proved to be ineffective.

**Approach/Background:** The subcontract includes the following tasks:
Task 1 Characterization and identification of lifetime in as-grown and processed crystalline silicon using PCD, DLTS and LBIC measurements, and FTIR for carbon and oxygen concentrations.
Task 2 Study of the synergistic effects of phosphorous and aluminum gettering
P and Al gettering will be performed individually and in combination on various PV materials. Al gettering will be investigated using both evaporated and screen printed Al layers on the back surface, followed by a high temperature alloying. Particular emphasis will be placed on screen printed Al gettering.
Task 3 Study of boron gettering and BSF formation. A low-cost process sequence will be developed to fabricate P and B co-gettered cells, and to examine the synergistic effects.
Task 4 (rapid thermal gettering-RTG): RTG will be studied individually and in combination with P, Al, and boron gettering. Various PV materials will be first processed in RTP or UV-RTP, followed by various heat treatments. Initial studies will be conducted by PCD, DLTS, and LBIC analysis and verified by final cell efficiency in the optimum processes.
Task 5 (hydrogen passivation by forming gas anneal and PECVD nitridation): FGA and PECVD nitridation anneal will be performed, including varying the P and Al diffusion temperatures to alter the surface concentrations and vacancy injection. Physical models will be developed.
Task 6 (fabrication of high efficiency cells by integrating synergistic effects of gettering and passivation techniques): low-cost process sequences will be developed by integrating several of optimized synergistic effects in previous tasks.

**Status/Accomplishments:**

**Planned FY 1999 Milestones:** Complete task 1 mc-Si studies; complete task 2; substantially complete task 3; start task 4; start task 5.

**Major Reports Published in FY 1998:** 1998 NREL Annual Report

**Major Articles Published in FY 1998:** 8th Workshop on Silicon Solar Cell Materials and Processing

# Hydrogen-Defect Interactions Relevant to Si Solar-Cell Fabrication Studied by Vibrational Spectroscopy

| **Contract #:** XCE-8-18684-01 | **Contract Period:** 8/1/98–7/31/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Lehigh University<br>Bethlehem, PA18015 | |
| | **Organization Type**: CU | **Congressional District:** 15 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>M. Stavola<br>**Phone:** 610-758-3946 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1998: $29,900 | **Cost Share Funding:** |

**Project Objective:** The objective of this subcontract is to initiate a study in which vibrational spectroscopy is used to probe the introduction and subsequent defect reactions of hydrogen in crystalline Si using end-illumination of the sample. The goal of these studies is to provide new information about the interactions of hydrogen with native vacancies and interstitials in Si and to explore the possible role of these defects during hydrogen introduction.

**Approach/Background:** Even though hydrogen is commonly introduced into solar-grade Si to reduce the deleterious effects of deep level defects, the mechanism for hydrogen introduction during low temperature processing steps and the subsequent interactions of hydrogen with defects and impurities are not well understood. A number of techniques are used to study hydrogen-defect interactions which include IR absorption spectroscopy. However, it is difficult to get good signals by conventional use of spectroscopy because the absorption coefficient of hydrogen in silicon is very small. A method to overcome this problem is to increase the optical path within the sample by shining the IR beam into the sample from one of the ends. The light is then totally reflected at the surfaces of the samples, enhancing the absorption of light within the sample.

This work will have two tasks, both of which involve the interaction of hydrogen with native defects in Si: Task 1. The first part of this study will investigate the interaction of hydrogen introduced into Si by an anneal in H2 gas with deep-level defects. It has recently been discovered that an anneal in H2 gas leads to the introduction of H2 molecules in the bulk of Si samples.1,2 These H2 molecules are then available to participate in reactions with other defects. The proposed experiments will create H2 molecules in bulk Si samples by annealing in hydrogen gas at 12508C and quenching to room temperature. These samples will then be irradiated with high energy electrons to produce vacancy and interstitial defects. These interactions of the native defects with hydrogen will be studied by vibrational spectroscopy. Task 2. The second part will study the enhancement in the incorporation of hydrogen into Si that has been reported for roughened surfaces.3 A possibility that has been suggested is that hydrogen interacts with native defects introduced at the roughened surface to enhance its introduction and diffusion.

**Status/Accomplishments:**

**Planned FY 1999 Milestones:** Submit results of task 1 + preliminary report on the results of task2.

**Major Reports Published in FY 1998:** 1998 NREL Annual Report

**Major Articles Published in FY 1998: 8th** Workshop on Silicon Solar Cell Materials and Processing

# Role of Point Defects and Impurities in Processing and Performance of Crystalline Silicon Solar Cells

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| **Contract #:** XD-2-11004-4 | **Contract Period:** 7/92–12/31/98 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Massachusetts Institute of Technology<br>Cambridge, MA 02139 | |
| | **Organization Type**: CU | **Congressional District:** 8 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>L. Kimerling<br>**Phone:** 617-253-5383 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1998: $35,000 | **Cost Share Funding:** |

**Project Objective:**
Investigate Al alloying as a process for simultaneous gettering and formation of back surface field

**Approach/Background:**
Aluminum gettering of multicrystalline (mc) silicon using rapid thermal processing: impurity gettering by aluminum alloying has worked very well for single crystal silicon. Some initial work on Al gettering of mc-Si has yielded excellent results. However, it is seen that the improvement in the material quality is not uniform. The objective of this research task is to apply the Al gettering techniques to mc-Si and develop processes that can uniformly improve the entire commercial silicon wafer.

**Status/Accomplishments:**
Have shown that RTP can lead to a uniform Si-Al contact and the bavck surface field

**Planned FY 1999 Milestones:**
Complete process development to optimize rapid thermal processing for mc-silicon wafers (Dec. 15, 1998)

**Major Reports Published in FY 1998:**
1998 NREL Annual Report

**Major Articles Published in FY 1998:**
8th Workshop on Silicon Solar Cell Materials and Processing

## Crystalline Silicon

# Characterization and Ti Gettering of PV Substrates

| **Contract #:** XAF-8-17607-03 | **Contract Period:** 1/29/98–1/28/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | North Carolina State University<br>College of Engineering, Box7916<br>2152 Burlington<br>Raleigh, NC 27695-7916 | |
| | **Organization Type**: CU | **Congressional District**: 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>G. Rozgonyi<br>**Phone:** 919-515-2934 **Fax:** 919-513-1699 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $105,000 | **Cost Share Funding:** |

**Project Objective:** The objective is to develop LMPCD as a tool for characterizing PV substrates and to evaluate possibility of using Ti gettering to improve quality of photovoltaic silicon wafers.
**Approach/Background:** The tasks include:

Task 1 (improve LMPCD and characterize PV substrates): LMPCD technique will be developed to ensure its compatible with making measurements on PV substrates. Of particular interest are parameters like resistivity, range of the minority carrier lifetime, and flatness. Furthermore, Frequency Resolved Microwave Spectroscopic capability will be added to the system. The new system capabilities will be applied to characterize impurity precipitation, defect clusters, and impurity dissolution in PV substrates.

Task 2 (investigate Ti gettering with subsequent oxidation of Ti to TiO2): Ti gettering, with and without Al co-gettering, will be explored to determine effectiveness of such a process in solar cell fabrication.

**Status/Accomplishments:**
LMPCD technique completed

**Planned FY 1999 Milestones:**
- design a wavelength variable LM-PCD system along with an optical excitation source for Frequency Resolved Microwave Spectroscopy,
- use this frequency resolved technique to characterize PV substrates supplied by NREL,
- perform preliminary experiments on thin film gettering program using magnetron sputtering for external gettering with Ti and Al,

**Major Reports Published in FY 1998:**
1998 NREL Annual Report

**Major Articles Published in FY 1998:**
8th Workshop on Silicon Solar Cell Materials and Processing

## Crystalline Silicon

# Theoretical Analysis of Hydrogen-Vacancy-Impurity Formation and Dissociation

| **Contract #:** XAX-5-15230-01 | **Contract Period:** 6/15/98–6/14/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Texas Tech. University<br>Lubbock, TX 79409 | |
| | **Organization Type**: CU | **Congressional District:** 19 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>S. Eistreicher<br>**Phone:**806-742-3723 **Fax:** 806-742-1182 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $49,900 | **Cost Share Funding:** |

**Project Objective:** The objective of the research under this modification is to give the basic understanding on the interactions between fundamental defects (vacancies and self-interstitials) and species that can passivate them (hydrogen) or worsen them (transition metals). Because Fe is very complicated to deal, Cu will be used as the test case.

**Approach/Background:** The previous theoretical analysis of hydrogen in silicon provided information regarding the precipitation of vacancies (in particular the ring-hexavacancy), the dynamics of vacancy-H2 and self-interstitial-H2 interactions. These results have been very valuable and provide a straightforward explanation for much of the experimental results obtained at NREL. There is further interest in understanding the interactions of interstitial H with various vacancy clusters. Of particular interest is to see how a single H affects the energy levels associated with some complicated defect such as a pentavacancy. Will a single H change a lot or just shift one level out of the gap? Will H activate the hexavancy, etc? This type of microscopic information will provide insights as to what happens when H interacts with dislocations. It is also necessary to perform analysis of H interactions with transition metals. This work has just begun in the present subcontract. Some of the work done on H-Cu interactions shows that H doesn't like to be nearby. This also depends on the specifics of the complex under study. However, it is known that interstitial Cu, if neutral, will only weakly bind H, and if charged, won't bind at all. There are other configurations that need to be addressed. The subcontractor will apply an ab-initio tight-binding molecular-dynamics simulations, developed in previous the contract, to develop theoretical models aimed at studying H interactions with transition metals (TM's). This study is expected to lead to the understanding of the mechanisms of TM impurity passivation

**Status/Accomplishments:**
Calculations on H-V interactions completed.

**Planned FY 1999 Milestones:**
Pursue the transition metal work, gain insight into the interactions between H and selected transition metal complexes, and provide report of the preliminary results of Fe-H interactions.

**Major Reports Published in FY 1998:**
1998 NREL Annual Report

**Major Articles Published in FY 1998:**
8th Workshop on Silicon Solar Cell Materials and Processing

## Crystalline Silicon

# Impurity Precipitation, Dissolution, and Gettering in PV Silicon

| **Contract #:** XAF-8-17607-04 | **Contract Period:** 1/25/98–1/24/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of California Berkeley<br>Dept. of Materials Science<br>587 Evans Hall<br>Berkeley, CA 94720 | |
| | **Organization Type**: CU | **Congressional District**: 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>E. Weber<br>**Phone:** 510-642-0205 **Fax:** 510-642-2069 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $140,000 | **Cost Share Funding:** |

**Project Objective:** The objective is to study regions of defect clusters, identify the nature of impurity precipitates, and develop methods to getter such impurities. This is to be accomplished by: 1) gaining an understanding of the nature of impurity precipitation and dissolution in regions of defect clusters; 2) measuring recombination activity of various precipitates; 3) using this knowledge to design low-cost processes to improve the regions in silicon containing defect clusters.

**Approach/Background:** The subcontract includes the following tasks:
Task 1 (Precipitation and Dissolution of Impurities): DLTS, TID will be used to measure the concentration of impurities in both single and polycrystalline FZ materials, before and after the processes, in which impurities such as iron, copper, and Ni are intentionally introduced. Other techniques such as SPV, synchrotron generated X-ray fluorescence, EBIC, TEM will help to characterize other properties. The amount of precipitated impurity in the bulk is then the initial concentration minus the dissolved concentration. This approach should provide a basis for understanding precipitation and dissolution of intentionally introduced contaminants around specific types of defects. Barriers to dissolution will be measurable.

Task 2 (Recombination Activity): samples that have undergone various precipitation and dissolution steps will be used to determine which impurities, precipitates, and defects have the lowest recombination activity. Recombination activity of specific defects will be analyzed using EBIC and SPV.

Task 3 (Gettering), aluminum gettering will be used with both FZ and PV grade silicon samples to study the interaction of specific types of defects with impurities. The segregation coefficient of impurities in the silicon/aluminum system will be determined

**Status/Accomplishments:**

**Planned FY 1999 Milestones:**

**Major Reports Published in FY 1998:**
1998 NREL Annual Report

**Major Articles Published in FY 1998:**
8th Workshop on Silicon Solar Cell Materials and Processing

## Crystalline Silicon

# Optimization of Gettering Processes for PV Silicon

| **Contract #:** XD-2-11004-5 | **Contract Period:** 1/15/98–6/30/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455, **Fax:** 202-586-8148 | University of South Florida<br>Center for Microelectronics Research<br>Tampa, FL 33620 | |
| | **Organization Type**: CU | **Congressional District**: 11 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>S. Oststapenko<br>**Phone:** 813-974-2031 **Fax:** 813-974-3610 | |
| **Technical Monitor:**<br>B. Sopori<br>**Phone**: 303-384-6683<br>**Fax**: 303-384-6684 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $30,000 | **Cost Share Funding:** |

**Project Objective:**
Investigate possibility of Ultrasound Treatment (UST) as a method to improve the minority carrier diffusion length of defect cluster regions

**Approach/Background:**
In the previous work performed by USF, it was shown that the Ultra Sound Treatment (UST) can, in some cases, enhance the minority carrier diffusion length of low-cost commercial silicon substrates. However, there was not enough work done to show that the cell performance actually increases with such a process. Limited amount of work done, in collaboration with NREL, showed that the solar cells that went through the UST did exhibit improvements in the dark current, but no significant changes were observed on the cell performance. It may be concluded, on the basis of this very limited work, that the improvement in the cell performance produced by the UST is a light dependent mechanism. Because of a large interest in the possible advantage of UST, it is important to perform work that can establish a reasonable data-set to decipher whether such a process has a potential to improve the cell performance.

**Status/Accomplishments:**
UST, followed by optical processing has shown significant improvement in the minority carrier diffusion length of defected regions in commercial PV silicon.

**Planned FY 1999 Milestones:**
Demonstrate improvement in the performance of small-area solar cells fabricated on defected regions of commercial PV silicon substrates.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Crystalline Silicon Research

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|---|---|
| **Contract #:** AX-5152 | **Contract Period:** 6/11/92–10/31/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | U.S. Filter Corporation<br>Albuquerque, NM | |
| | **Organization Type**: CU | **Congressional District:** 05 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)** | |
| **Technical Monitor:**<br>J. Tingley<br>**Phone:** 505-844-3774<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1997: $6,000<br>1998: $10,0000 | **Cost Share Funding:** |

**Project Objective:** Continual use contract for deionized water.

**Approach/Background:** Maintain deionized water supply.

**Status/Accomplishments:** Allows for successful wafer processing in the PDFL.

**FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Environmental, Health, Safety and Resource Characterization

# Photovoltaic Environmental, Health and Safety Assistance Center

| **Project #:** PV-1516 | **Contract Period:** 10/1/97–9/30/98 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Brookhaven National Laboratory<br>Building 830<br>Upton, NY 11973-5000 | |
| | **Organization Type**: FF | **Congressional District:** 1 |
| **Directing Organization**:<br>Brookhaven National Laboratory<br>Building 830<br>Upton, NY 11973-5000 | **Principal Investigators**<br>V.M. Fthenakis **Phone:** 516-344-2830 **Fax:** 516-344-4486<br>P.D. Moskowitz **Phone:** 516-344-2017 **Fax:** 516-344-4486 | |
| **Technical Monitor:**<br>A. Bulawka<br>**Phone**: 202-586-5633<br>**Fax**: 202-586-5127 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1994: $400,000 1997: $300,000<br>1995: $380,000 1998: $300,000<br>1996: $300,000 | **Cost Share Funding:** |

**Project Objective:** Assist the safe and environmentally friendly operation of photovoltaic facilities and products, extending from R&D to manufacturing and deployment. The specific objectives of the Center are to prevent accidents, reduce EH&S occupational and public risks, and reduce environmental and safety related costs. These objectives are paramount to the economic viability and public acceptance and support of PV systems.

**Approach/Background:** The BNL Center conducts the following types of activities: 1) It provides direct support to DOE Headquarters, the National Renewable Energy Laboratory (NREL) and Sandia National Laboratory (SNL) to ensure that the operations of their facilities and those of their contractors are operated in an environmentally responsible manner. 2) It conducts EH&S audits, safety reviews and incident investigations, as needed. 3) It assists the photovoltaic industry to identify and examine potential EH&S barriers and hazard control strategies for new photovoltaic material, process and application options before their large-scale commercialization. To facilitate the application of knowledge derived from the above activities, BNL hosts workshops, tutorials and symposia, uses electronic mail and a web page, and publishes articles in the peer-reviewed literature (140 publications up-to-date).

**Status/Accomplishments:** In FY98, we handled more than twenty requests for assistance and information from industry, universities, and private and government agencies; we conducted new studies on recycling, toxicology of CdTe, CGS and CGS, $H_2Se$ explosion, and $CO_2$ emissions' reduction; and we assisted BP Solar, Siemens Solar, and Solar Cells Inc. with facility-specific environmental and safety studies. Also, we organized (with NREL) a two-day workshop on recycling, PV for greenhouse gas reduction and the Million Roof Initiative, made 3 conference presentations and published (or submitted for publication) 9 papers.

**Planned FY 1999 Milestones:** In FY99, we will assist the DOE, NREL and Sandia and answer public inquires, on PV EH&S issues, as needed. Regarding our industry outreach, we plan to handle requests for facility specific EH&S studies from Siemens Solar and BP Solar, and we will follow up to inquires from EPV, Astropower, ITN, and ASE Americas. Regarding industry-wide EH&S, we will investigate: Potential issues related to the fast deployment of residential roof systems expected from the Million Roof Initiative; handling of CdTe, CIS and CGS feedstock materials; cost effective ways for handling PV manufacturing waste; the infrastructure for recycling PV waste and modules; and environmentally friendly alternatives to Pb soldering. Also, we plan to initiate a study on the on local/regional air pollution benefits from PV deployment.

**Major Articles Published in FY 1998:**

Fthenakis V.M., Prevention and Control of Accidental Releases of Hazardous Materials in PV Facilities, *Progress in Photovoltaics,* 6, 91-98, 1998.

Fthenakis V.M. and Lee J.C., The Impact of Photovoltaics on $CO_2$ Emissions' Reduction in the US, *The World Resource Review*, 10(3), 435-445, 1998.

Fthenakis V.M. and Moskowitz P.D., The Value and Feasibility of Proactive Recycling, 15th NCPV Photovoltaics Program Review Meeting; Denver, CO, 1998*; AIP Conference Proceedings* (in press)]

# Apollo Thin Film Process Development

| **Contract #:** ZAK-7-17619-27 | **Contract Period:** 5/1/98–4/30/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | BP Solar Inc.<br>2300 North Watney Way<br>Fairfield, CA 94533 | |
| | **Organization Type**: IN | **Congressional District:** 7 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D.W. Cunningham<br>**Phone:** 707-438-3818 **Fax:** 707-428-7878 | |
| **Technical Monitor:**<br>H S. Ullal<br>**Phone**: 303-384-6486<br>**Fax**: 303-384-6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>BP Solar Inc. |
| | **DOE Funding Allocation:**<br>1998: $151,432 | **Cost Share Funding:**<br>1998: $ 260,068 |

**Project Objective:**
The objectives of this subcontract are to optimize CdTe electroplating and CdS chemical bath deposition operations, conduct process development, determine device performance and reliability, optimize laser process techniques, and enhance waste treatment and abatement systems to achieve zero-discharge.

**Approach/Background:**
BP Solar is currently introducing the Apollo® CdTe technology at its new Fairfield, CA production plant. The plant in California is designed and built to produce its thin-film module in high volume. This commitment is the result of BP Solar's extensive R&D program over the past ten years which has been successful in developing and characterizing a stable 8% CdTe 929 $cm^2$ module at the limited pilot line level. At Fairfield, BP Solar Inc. will scale up the Apollo® CdTe process to produce a 5,518 $cm^2$ and ultimately a 9,449$cm^2$, monolithic CdS/CdTe module.

**Status/Accomplishments:**
Produced a roof top system using 25W Apollo® modules to analyze outdoor stability and reliability on a monthly basis.
Achieved UL certification for Apollo® model BP-925L module.

**Planned FY 1999 Milestones:** Produce glass-to-glass encapsulated CdTe modules.( 5,518 $cm^2$ ) with aperture-area efficiency of 8%.

**Major Reports Published in FY 1998:**
Presentation given on TCLP sampling protocol at PV and the Environment Workshop, Keystone, CO, July 1998.

**Major Articles Published in FY 1998:**
None.

# Microstructure of Amorphous Silicon Based Solar Cell Materials by Small Angle X-Ray Scattering

| **Contract #:** XAN-4-13318-04 | **Contract Period:** 4/6/94–6/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Colorado School of Mines<br>1500 Illinois St.<br>Golden, CO 80401 | |
| | **Organization Type**: CU | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. Williamson<br>**Phone:** 303-273-3837 **Fax:** 303-273-3919 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $45,000 1997: $78,369<br>1995: $80,267<br>1996: $84,971 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States ensuring that this industry remains a world leader in the amorphous silicon technology; help the U.S. amorphous silicon PV industry to achieve the DOE PV Program milestone of 10% stable efficiency commercial thin-film modules; help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Characterize the microstructure of amorphous silicon and alloys using small angle X-ray scattering technique.

**Status/Accomplishments:** Structural characterization done of all recent a-Si:H and a-SiGe:H layers deposited by new techniques (hot-wire, ECR, hydrogen dilution).

**Planned FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Report to be published.

**Major Articles Published in FY 1998:**
*Solid State Communications* 108 (1998) 419.
*J. Non-Crystalline Solids* 227-230 (1998) 128.
*MRS Symposia Proceedings* 467 (1998) 657.

# Nanostructure of a-Si:H and Related Alloys by Small-Angle Scattering of Neutrons and X-rays

| **Contract #:** XAK-8-17619-31 | **Contract Period:** 5/22/98–7/21/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King, **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer, **Phone:** 202-586-2455, **Fax:** 202-586-8148 | Colorado School of Mines<br>1500 Illinois St.<br>Golden, CO 80401 | |
| | **Organization Type**: CU | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. Williamson and D.W.M. Marr<br>**Phone:** 303-273-3837 **Fax:** 303-273-3919 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $37,000 | **Cost Share Funding:** |

**Project Objective:** To improve the understanding of which nanostructural features are related to electronic materials properties that determine the performance of a-Si:H based solar cells. The project will determine whether small-angle neutron scattering can be used to determine hydrogen-related nanostructures and any changes that might occur in them during light soaking. The ASAXS technique shall be established as to determine non-uniform Ge incorporation into a-SiGe:H material. Determine the role of medium range order in light stability and other device behavior.

**Approach/Background:** Use both small-angle neutron (SANS) and x-ray scattering (SAXS) and conventional wide-angle x-ray diffraction techniques to investigate the nanostructures of amorphous and microcrystalline silicon-related solar cell materials and correlate them with optoelectronic and device properties. Extensive prior work with SAXS has established its value in correlating certain nanostructural features with degraded solar cell performance.

**Status/Accomplishments:** A non-uniform Ge distribution in a-SiGe:H materials has been demonstrated by ASAXS (see ref. 1 below). High levels of ion bombardment can eliminate this non-uniformity but other defects associated with the bombardment are detrimental to devices. Improvement in medium range order has been detected via x-ray linewidth studies of high-hydrogen-diluted a-Si:H and this correlates with improved light stability and reduced defect densities determined by capacitance profiling.

**Planned FY 1999 Milestones:** Perform and evaluate a first set of experiments with SANS to establish its viability for determining hydrogen nanostructure. Perform additional ASAXS experiments with various a-SiGe:H materials to establish the degree of Ge non-uniformity in current device-quality material. Further examine medium range order in a-Si:H related materials to establish its importance in light stability and device behavior.

**Major Reports Published in FY 1998:** None; new subcontract.

**Major Articles Published in FY 1998:**

"Nanostructured Ge Distribution in a-SiGe:H Alloys from Anomalous Small-Angle X-Ray Scattering Studies", G. Goerigk and D.L. Williamson, *Solid State Commun*. 108, 419 (1998).
"Structural Information on a-Si:H and Its Alloys from Small-Angle Scattering", D.L. Williamson, in *Properties of Amorphous Silicon and its Alloys*, edited by T. Searle, EMIS Data Review Series No. 19 (INSPEC, London, 1998) p. 47.
"Structural Defects and Hydrogen Clustering in Amorphous Silicon", S. Acco, D.L. Williamson, S. Roorda, W.G.J.H.M. van Sark, A. Polman, and W.F. van der Weg, *J. Non-Cryst. Solids* 227-230, 128 (1998).
"Observation of Improved Structural Ordering in Low H Content, Hot Wire Deposited a-Si:H", A.H. Mahan, D.L. Williamson, and T.E. Furtak, *Mater. Res. Soc. Symp. Proc*. 467, 657 (1998).

# Process Development and Basic Studies of Electrochemically Deposited CdTe-Based Solar Cells

| **Contract #:** XAK-8-17619-28 | **Contract Period:** 5/1/98–4/30/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455, **Fax:** 202-586-8148 | Colorado School of Mines<br>1500 Illinois St.<br>Golden, CO 80401-1887 | |
| | **Organization Type**: CU | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>V. Kaydanov — **Phone:** (303) 273-3156, **Fax:** (303) 273-3919<br>T.R. Ohno — (303) 273-3847, (303) 273-3919 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: (303) 384-6480<br>**Fax**: (303) 384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $251,426 | **Cost Share Funding:** |

**Project Objective:** Advance the processing for high-performance stable CdTe photovoltaic devices, by: (1) advancing the understanding how the basic electronic properties of CdTe thin film solar cells are related to composition, structure and processing procedure of the constituting layers; (2) studying microscopic processes in different parts of the cell responsible for degradation of electronic properties as a function of stress conditions; (3) optimizing the composition of the constituting layers, deposition procedures and postdeposition treatments to enhance cell performance; and (4) contributing to the development of accelerated lifetime prediction tests for the CdTe solar cells.

**Approach/Background:** Study electronic properties of polycrystalline thin films, in particular of grain boundaries, and devices prepared and stressed under varying conditions using variety of experimental methods and models. Optimize processing procedure of CdS/CdTe structure, composition and processing procedure of the front and back contacts.

**Status/Accomplishments:** A new method for studies of parameters of main diode and the Back Contact Schottky diode was developed based on analysis of dV/dJ dependencies on current and bias. $SnO_2$ thin films were prepared by APCVD and studied using a variety of methods. It was shown that grain boundaries do not influence resistivity/mobility; scattering by impurity ions screened by free carriers is a dominating mechanism.

**Planned FY 1999 Milestones:** Complete and apply new equipment and measurement procedures for characterizing macroscopic and microscopic properties of polycrystalline thin films of CdS, CdTe and TCO. Conduct stress stability tests on cells. Establish major mechanisms for cell degradation.

**Major Reports Published in FY 1998:**
None

**Major Articles Published in FY 1998:**
*NPCV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998*; AIP Conference Proceedings (in press), four articles.

## Thin-Film Technologies

# Process of Electrochemically Deposited CdTe-Based Solar Cells

| **Contract #:** XAF-S-14142-11 | **Contract Period:** 4/28/95–6/15/98 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455, **Fax:** 202-586-8148 | Colorado School of Mines<br>1500 Illinois St.<br>Golden, CO 80401-1887 | |
| | **Organization Type**: CU | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J.U. Trefny — **Phone:** (303) 273-3833, **Fax:** (303) 273-3040<br>V. Kaydanov — (303) 273-3156, (303) 273-3919<br>T.R. Ohno — (303) 273-3847, (303) 273-3919 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: (303) 384-6480<br>**Fax**: (303) 384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1995: $216,842 1997: $233,557<br>1996: $152,432 1998: $127,848 | **Cost Share Funding:** |

**Project Objective:** Investigate the processing of electro-deposited CdTe-based Solar cells in order to enhance device performance and establish processing dependent variations. The effects of the properties of other layers used in the device (TCO, CdS, ZnTe, metallization) on the device performance will be established as well as some mechanisms of cell degradation. The research will be carried out in close collaboration and in support of the NREL-managed CdTe research team. This project supports the DOE goal set for 2005 of achieving commercial, low cost, 15% efficient thin-film photovoltaic modules.

**Approach/Background:** Optimize cell performance and study degradation processes at the School of Mines and in collaboration with National CdTe Team.

**Status/Accomplishments:** Degradation of CdS/CdTe/ZnTe:Cu/Au solar cells was studied under stress conditions. It was shown that Cu dopant influences significantly cell stability. Electromigration of Cu should be taken into account when predicting long-term cell stability. It was demonstrated that more uniform S distribution in the CdTe layer is beneficial for the cell performance.

**Planned FY 1999 Milestones:** N/A

**Major Reports Published in FY 1998:** *Final Technical Report, March 20, 1995 to June 15, 1998*, draft version accepted for publication

**Major Articles Published in FY 1998:**
*Proceedings of Material Research Soc. Symp.* **485**, 1998, pp. 203-208.
*Proceedings of the 2nd World Conf. on Photovoltaic Solar Energy Conversion*, July 6-10, 1998, Vienna, Austria (one joint paper with NREL).

## Thin-Film Technologies

# Device Physics of Thin-Film Polycrystalline Cells and Modules

| **Contract #:** XAX-4-14000-01 | **Contract Period:** 12/6/93–3/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Colorado State University<br>Fort Collins, CO 80523 | |
| | **Organization Type**: CU | **Congressional District:** 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J. Sites<br>**Phone:** 970-491-6206 **Fax:** 970-491-7947 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $95,995 — 1997: $105,000<br>1995: $100,000 — 1998: 0<br>1996: $110,000 | **Cost Share Funding:** |

**Project Objective:** The objectives of the work include the separation and quantification of individual losses in specific thin-film solar cells, the detailed characterization of small modules, and the presentation of a viable model for the forward-current loss mechanism to meet the DOE goal set for the year 2005 to achieve commercial, low-cost, 15% efficient thin-film photovoltaic modules.

**Approach/Background:** Provide standardized device analyses for CuInSe2- and CdTe-based solar cells.

**Status/Accomplishments:** Carried out substantial device analyses for the CIS and CdTe teams. PI provides team leadership for national CIS subteam.

**Planned FY 1999 Milestones:** Project completed.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Phase 3 Subcontract Report, NREL/SR-520-23589 (October 1997).
Final Report, to be published.

**Major Articles Published in FY 1998:**
*Proceedings of the 26th IEEE PV Specialists Conference,* Anaheim, CA (9/29-10/3/97), article on page 387.

## Thin-Film Technologies

# Device Physics of Thin-Film Polycrystalline Solar Cells

| **Contract#:** XAK-8-17619-07 | **Contract Period:** 1/20/98–1/19/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Colorado State University<br>Department of Physics<br>Fort Collins, CO 80523 | |
| | **Organization Type:** CU | **Congressional District:** 4 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>James R. Sites<br>**Phone:** 970-491-5850 **Fax:** 970-491-7947 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1998: $140,318 | **Cost Share Funding:** |

**Project Objective:** To (1) characterize and quantitatively separate individual losses in CI(G)S and CdTe cells and small modules, (2) explore mechanisms that allow small changes in impurity materials to have a significant performance impact, (3) develop a micron-size light probe, (4) characterize stability and transient response of cells at elevated temperature, and (5) integrate CdTe grain-boundary modeling with experimental data.

**Approach/Background:** Partnership with industry, NREL, and other universities to form an effective division of labor and communication network to collectively increase the commercial viability of thin-film polycrystalline modules.

**Status/Accomplishments:** (1) Systematic and quantitative study of the beneficial effect of sodium incorporation in $CuInSe_2$-based solar cells. (2) Documentation of elevated-temperature induced changes in CdTe cells as a funtion of bias. (3) Construction of small-light-spot probe with micron stepping control. (4) Quantitative loss analysis of several $CuInSe_2$ and CdTe cells.

**Planned FY 1999 Milestones:** (1) Use small-spot probe to characterize cells at the grain level, (2) clarify the problems of copper in contacting CdTe, (3) compare air and nitrogen ambients in elevated-temperature stress tests.

**Major Reports Published in FY 1998:** None (new subcontract).

**Major Articles Published in FY 1998:**


"Device and Materials Characterization in Manufacturing," J. Sites, J. Rand, L.L. Kazmerski, and J.E. Phillips, *Progress in Photovoltaics* **5,** 371 (1997).

"Impact of Sodium in the Bulk and Grain Boundaries of $CuInSe_2$," J.E. Granata, J.R. Sites, and S. Asher, Proc. 2nd World Conf. on Photovoltaic Solar Electricity (1998).

"Blue-Photon Modification of Nonstandard Diode Barrier in $CuInSe_2$ Solar Cells," I.L. Eisgruber, J.E Granata, J.R. Sites, J. Hou, and J. Kessler, *Solar-Energy Materials and Solar Cells* **53,** 367 (1998).

"Losses Due to Polycrystallinity in Thin Films," J.R. Sites, J.E. Granata, and J.F. Hiltner, *Solar-Energy Materials and Solar Cells* **55,** 43 (1998).

## Thin-Film Technologies

# Development of a Thin-Film Based "Micro-Concentrator" Photovoltaic Technology

| **Contract #:** ZAK-8-17619-25 | **Contract Period:** 5/1/98–4/30/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | DayStar Technologies, Inc.<br>303 S. Broadway, B-415<br>Denver, CO 80209 | |
| | **Organization Type**: IN | **Congressional District:** 1 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>John R. Tuttle, Ph.D.<br>**Phone:** 303-722-4197 **Fax:** 303-742-1899 | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone**: 303.384.6441<br>**Fax**: 303.384.6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>DayStar Technologies, Inc. |
| | **DOE Funding Allocation:**<br>1998: $38,383 | **Cost Share Funding:**<br>1998: $8,754 |

**Project Objective:** DayStar Technologies, Inc. is developing a "micro-concentrator" PV module packaging technology as a reduced cost alternative to conventional solar cell and module products. The optical lens and cell interconnect scheme was originally designed for use with thin-film solar cell components fabricated on flexible, metallic substrates such as sheet stainless steel. Daystar will work through development issues in: 1) cell design, performance, and reliability operated at 2-8 suns of concentration; 2) cell modification, interconnect, and lamination to optical lens sheet; and 3) lens performance and module packaging. The solar cell materials presently under consideration are triple junction a-Si (United Solar) and single junction ZnO / $Cu(In,Ga)Se_2$.

**Approach/Background:** Replacing costly solar cell material with inexpensive ($\$20/m^2$) optical lens material is, by design, an effective means for reducing the manufacturing cost of PV modules. DayStar has created a module design that more closely emulates the mechanical nature of conventional flat-plate PV products and realizes significant cost savings through optical concentration of 2-8 suns. In order to achieve these benefits, technical and cost issues pertaining to cell modification (grid design / dicing), interconnect, component lamination, and optics performance require investigation.

**Status/Accomplishments:** Under the present contract, CIGS cells (in a geometry compatible with our concentrator module package) were fabricated on 0.002"-0.007" sheet stainless steel with performance ranging from 13-16%. These cells were subjected to 50-hour reliability testing under 5-suns at operating temperatures of 50□C and demonstrated superior performance relative to the same cells at 1-sun/25□C. Stabilized, triple junction a-Si cells on sheet stainless steel have also been tested under identical conditions and demonstrated similar performance characteristics. Series connected 10-cell strings show little or no performance variations from the individual cells. DayStar's optical lens (patent pending) has been demonstrated, though optimal performance is still being pursued. A 7.2% (active-area) 25-cm2 CIGS-based mini-module has been measured at NREL's outdoor measurement facility. Improvements in optical performance and interconnect reliability for thin-film cell components is required in order to reach the desired 10% module performance benchmark.

**Planned FY 1999 Milestones:** The desired milestones for FY'99 under this subcontract include: 1) reproducible 13% total-area cell performance for CIGS-based cells; 2) reliable 12% 10-20 cell strings; 3) >10% (active-area) 50-$cm^2$ CIGS-based mini-modules; and 4) > 6% 50-$cm^2$ a-Si based mini-modules. The latter two milestones require reflectivity performance within the optics of > 85%.

**Major Articles Published in FY 1998:**

J.R. Tuttle, E.D. Cole, T.A. Berens, A. Szalaj, J. Keane, J. Alleman, "A Novel Flat-Plate PV Concentrator Package", *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

J.R. Tuttle, E.D. Cole, T.A Berens, J. Keane, and J.Alleman, "A Crystalline and Thin-Film Cell PV Concentrator Package", *Proceedings of the 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion*, Vienna, Austria, 6-10 July 1998 (in press).

# Development of High, Stable-Efficiency Triple-Junction a:Si Alloy Solar Cells

| **Contract #:** ZAN-4-13318-11 | **Contract Period:** 7/19/94–2/15/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Energy Conversion Devices, Inc.<br>1675 West Maple Road<br>Troy, MI 48084 | |
| | **Organization Type**: IN | **Congressional District:** 12 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>X. Deng<br>**Phone:** 810-280-1900 **Fax:** | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone**: 303-384-6441<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>Energy Conversion Devices, Inc.. |
| | **DOE Funding Allocation:**<br>1994: $140,000 — 1997: $250,000<br>1995: $318,000 — 1998: $48,000<br>1996: $244,000 | **Cost Share Funding:**<br>1994: $326,000 — 1997: $570,000<br>1995: $742,000 — 1998: $102,000<br>1996: $569,000 |

**Project Objective:** The objectives of this subcontract are to develop a cost-effective amorphous silicon PV technology; help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Improve throughput by 20% over baseline and decrease silicon alloy feedstock by 20% without loss in stabilized module performance. Demonstrate 1 $ft_2$ a-Si modules of at least 9% efficiency for a run of 18 modules with over 75% yield.

**Status/Accomplishments:** Developed a modified VHF deposition process for the microcrystalline silicon p-layer deposition and demonstrated a 6% improvement in Jsc and 10% improvement in efficiency; achieved deposition of stable a-Si i-layer at deposition rate up to 15 A/s; demonstrated the feasibility of depositing high quality ZnO by sputter metal Zn target for cost reductions.

**Planned FY 1999 Milestones:** None; contract completed.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Technical Report, NREL/SR-520-24580, (April 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)
X. Deng, et al., Materials Research Society Proceedings Volume 467, 795 (1997).
D. Han, et al., *Phys. Rev. B*, 55, 15619 (1997).
Proceedings of 26th IEEE Photovoltaic Specialists Conference, pages 591 and 607 (1997).

# Thin-Film Technologies

## Use of Very High Frequency Plasmas to Prepare a-Si:H Based Triple-Junction Solar Cells at High Deposition Rates

| **Contract#:** ZAK-8-17619-18 | **Contract Period:** 3/11/98–5/10/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Energy Conversion Devices, Inc.<br>1675 West Maple Rd.<br>Troy, MI 48084 | |
| | **Organization Type:** IN | **Congressional District:** 12 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>S. J. Jones<br>**Phone:** 248-362-4780 **Fax:** 248-362-0012 | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone:** 303-384-6441<br>**Fax:** 303-384-6430 | **B&R Code:** EB22 | **Cost Share Information:**<br>ECD |
| | **DOE Funding Allocation:**<br>1998: $235,000 | **Cost Share Funding:**<br>1998: $235,000 |

**Project Objective:** To develop a very high frequency (70 MHz), plasma-enhanced, chemical vapor deposition process for the fabrication of intrinsic layers for high efficiency amorphous silicon-based triple-junction solar cells at high deposition rates. These intrinsic layers are either amorphous silicon or amorphous silicon germanium alloy materials. The goal is to prepare these materials at rates of 10 Å/s or higher while maintaining the cell efficiencies at the high values presently obtained for devices made using the standard 13.56 MHz frequency and low deposition rates (near 1 Å/s). Upon completion of a successful program, application of this high rate process to ECD's roll-to-roll solar cell production design will lead to higher machine throughput and reduced solar module cost.

**Approach/Background:** The deposition conditions used to prepare single-junction amorphous silicon (a-Si:H) and silicon germanium alloy (a-SiGe:H) cells by the very high frequency (VHF) technique will be optimized to obtain the highest cell efficiencies. These component cells will then be combined to create high efficiency a-Si:H/a-SiGe:H/a-SiGe:H triple-junction cells. The deposition conditions for these multi-junction cells will also be optimized to further increase the device performance. For the future incorporation of the technique into an ECD built roll-to-roll solar cell production line, cathode hardware designs will be tested which will allow for the uniform deposition of i-layers over a large area using the VHF technique and high deposition rates.

**Status/Accomplishments:** The following has thus far been accomplished:1) preparation of a single-junction a-Si:H cell with a stable 8.0% efficiency using the VHF technique and a 10 Å/s rate, 2) Preparation of a triple-junction cell with an initial (Pre-light soaked) 10% efficiency using the VHF technique and a 10 Å/s rate for all of the i-layers.

**Planned FY 1999 Milestones:** The following are goals for this fiscal year: 1) preparation of a single-junction a-Si:H cell with a stable 8.4% efficiency using the VHF technique and a 10 Å/s rate and 2) preparation of a single-junction a-SiGe:H cell with a stable 2.8% red-light (630 nm filtered) efficiency using the VHF technique and a 10 Å/s rate.

**Major Reports Published in FY 1998:**
*None*

**Major Articles Published in FY 1998:**
*"Preparation of a-Si:H and a-SiGe:H i-layers for nip solar cells at high deposition rates using a very high frequency technique." S.J. Jones, X. Deng, T. Liu, and M. Izu, Mat. Res. Soc. Proc 1998 Spring Meeting (in press)*

*"Preparation of a-Si:H and a-SiGe:H nip cells at high rates using a 70 MHz VHF PECVD technique.", S.J. Jones, T. Liu and M. Izu, NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Thin-Film Technologies

# Thin-Film CIGS Photovoltaic Technology

| **Contract#:** ZAK-8-17619-21 | **Contract Period:** 4/16/98–4/15/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Energy Photovoltaics, Inc. (EPV)<br>276 Bakers Basin Road<br>Lawrenceville, NJ 08648 | |
| | **Organization Type:** IN | **Congressional District:** 4 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>A.E. Delahoy<br>**Phone:** 609-587-3000 **Fax:** 609-587-5355 | |
| **Technical Monitor:**<br>H.S. Ullal<br>**Phone:** 303-384-6486<br>**Fax:** 303-384-6430 | **B&R Code:** EB22 | **Cost Share Information:**<br>Energy Photovoltaics, Inc. (EPV) |
| | **DOE Funding Allocation:**<br>1995: $995,856 1997: $1062,801<br>1996: $1,029,429 1998: $510,500 | **Cost Share Funding:**<br>1995: $248,964 1997: $265,700<br>1996: $257,357 1998: $102,100 |

**Project Objective:** The objectives of this R&D program include: small area, high efficiency CIGS process development, and process transfer to large area (0.43 $m^2$) pilot line system; improved junction formation; ZnO process development; patterning operations, module fabrication and diagnostic testing; module encapsulation, qualification testing and outdoor monitoring.

**Approach/Background:** EPV operates a 4-source, R&D scale (up to 900 $cm^2$) CIGS deposition system, together with cell and minimodule fabrication facilities, for CIGS process development. EPV also operates a complete pilot line for production of 4300 $cm^2$ CIGS modules. This line includes an in-line magnetron sputtering system (22" targets) and the large *Zeus* CIGS compound formation machine. The *Zeus* system contains three novel linear evaporation sources for material delivery and maintains glass flatness even at high temperatures. Large area CdS, laser scribing, and vacuum lamination facilities are also used. Special diagnostics are in place for early $V_{oc}$ and $J_{sc}$ checks, and also for non-destructive, local I-V curves on finished modules for mapping purposes.

**Status/Accomplishments:**
A new R&D scale process resulting in high cell voltages was developed and termed the FORNAX process.
Using the FORNAX process, a 10.2% 16-cell minimodule was prepared with cell voltages averaging 607 mV.

**Planned FY 1999 Milestones:**
Controlled deposition of Cu by linear source evaporation.
Fabricate CIGS modules with power output of 33 W and area of 0.43 $m^2$.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report,* NREL/BK-210-23607, (June 1998).
Delahoy, A.E.; Britt, J.S.; Kiss, Z.J. (1998). "CIS Photovoltaic Technology," Final Technical Report, NREL/SR-520-25713, 29pp. Available from NTIS, VA 22161.

**Major Articles Published in FY 1998:**
Delahoy, A.E.; Chorobski, D.; Ziobro, F.; Kiss, Z.J. "Baseline Process Development for Pilot Line Production of CIGS Modules," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

## Thin-Film Technologies

# CdTe Module Testing and Study of Transients and Irreversible Effects in CdTe Thin-Film Solar Cells

| **Contract #:** XCR-6-16773-01 | **Contract Period:** 05/23/96–11/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Florida Solar Energy Center, University of Central Florida<br>1679 Clearlake Road<br>Cocoa, FL 32952-5703 | |
| | **Organization Type**: CU | **Congressional District:** 15 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Neelkanth G. Dhere<br>**Phone:** 407-638-1442 **Fax:** 407-638-1010 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1996: $30,000 FY98: $5,000<br>1997: $5,000 | **Cost Share Funding:** |

**Project Objective:** Study the mechanisms of degradation if any in the CdTe PV modules.

**Approach/Background:** PV Materials Laboratory of FSEC has been studying the durability of PV modules. A small percentage of PV modules tend to degrade slowly in the harsh coastal climate. CdTe thin Film PV modules may be susceptible to degradation in the hot and humid climate. A detailed analysis may be able to point to degradation mechanisms if any of the CdTe thin film PV modules.

**Status/Accomplishments:** SCI solar modules were connected to a resistor as a fixed load because a replacement could not be found for the problematic maximum-power-point tracker. The following data were collected: voltage, current, irradiance, three back-of-module temperatures, ambient temperature beneath the solar array, atmospheric pressure, wind speed, and relative humidity. The analysis included only data with irradiance values larger than 900 $W/m^2$. Readings of PV power were normalized to 1000 $W/m^2$. During the summer months, apparently the normalized power was reduced because of the increasing load mismatch occurring at higher temperatures. Hence the present cycle was continued until September 1998 to verify full power recuperation at lower temperatures. More recent data showed a small reduction in the normalized power.

**Planned FY 1999 Milestones:** The monitoring will be continued.

**Major Reports Published in FY 1998:**

**Major Articles Published in FY 1998:**

## Thin-Film Technologies

# $CuIn_{1-x}Ga_xSe_2$ Thin Film Solar Cells

| **Contract #:** XAK-8-17619-12 | **Contract Period:** 02/11/98–02/10/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King J. Mazer<br>**Phone:** 202-586-1693 **Phone:** 202-586-2455<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Florida Solar Energy Center, University of Central Florida<br>1679 Clearlake Road<br>Cocoa, FL 32952-5703 | |
| | **Organization Type**: CU | **Congressional District:** 15 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Neelkanth G. Dhere<br>**Phone:** 407-638-1442 **Fax:** 407-638-1010 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $31,700 | **Cost Share Funding:** |

**Project Objective:** To develop selenization, sulfurization, and gallium incorporation techniques for the preparation of $CuIn_{1-x}Ga_xSe_{2-y}S_y$ thin films and solar cells. Apply the techniques developed during the study of the durability of crystalline silicon PV modules for the study of thin-film PV modules. Monitor the performance of thin-film PV modules in the hot and humid climate of Florida.

**Approach/Background:** Attempts made to optimize the bandgap of $CuIn_{1-x}Ga_xSe_2$ (CIGS) thin films by enhancing gallium incorporation resulted in the formation $CuIn_{0.5}Ga_{0.5}Se_2$ and $CuIn_{0.7}Ga_{0.3}Se_2$ phases, however, with poor morphology. Higher efficiencies are expected from $CuIn_{1-x}Ga_xSe_{2-y}S_y$ films having improved morphology and x of ~0.2 by replacing the second selenization by sulfurization and by Na addition in the form of $Na_2S$. A number of interesting techniques have been developed during study of durability of crystalline silicon PV modules. Some of these will be useful for the improving the durability of thin-film PV modules. Monitoring of thin-film modules in the hot and humid Florida climate will help in identifying any degradation mechanisms.

**Status/Accomplishments:** A quartz glass set up and a scrubber of $H_2S$ gas have been designed and the components have been acquired. It is being installed in a small furnace. A fume hood equipped with $H_2S$ detector is being shared with other projects. In the future, $CuIn_{1-x}Ga_xSe_{2-y}S_y$ thin film solar cells will be prepared by replacing the second selenization by sulfurization so as to optimize the bandgap and thus to achieve higher efficiencies. This set up will be used for these sulfurization experiments for the preparation of $CuIn_{1-x}Ga_xSe_{2-y}S_y$ thin films. Thin-film PV modules are being monitored at FSEC.

**Planned FY 1999 Milestones:** Continue testing of the SCI CdTe PV Array on the low-bay lab roof of FSEC and other CIGS and a-Si:H thin film PV modules at the FSEC test facility. Carry out selenization of ISET non-vacuum metallic precursors, gallium addition, selenization and Ga activation by heat treatment in nitrogen. Carry out selenization and sulfurization of metallic precursors prepared at the FSEC PV Materials Lab for preparation and characterization of $CuIn_{1-x}Ga_xSe_{2-y}S_y$ thin films and solar cells. Carry out experiments for the extraction of live cells from CdTe thin film PV modules.

**Major Reports Published in FY 1998:** none, new subcontract

**Major Articles Published in FY 1998:**
A poster paper entitled, "Band Gap Optimization by Gallium and Sulfur Incorporation in $CuIn_{1-x}Ga_xSe_{2-y}S_y$ Thin Films Prepared by Selenization-Sulfurization Process" at the 2nd World Photovoltaic Solar Energy Conference held at Vienna, Austria, during July 6-10, 1998.

## Thin-Film Technologies

# Process Development of Large-Area, Thin-Film CIGS Based PV Modules

| **Contract #:** ZAK-8-17619-04 | **Contract Period:** 02/05/98–02/04/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Global Solar Energy, LLC<br>5575 S. Houghton Rd.<br>Tucson, AZ 85747 | |
| | **Organization Type**: IN | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J. Britt<br>**Phone:** 520-546-6313 **Fax:** 520-546-6318 | |
| **Technical Monitor:**<br>H.S. Ullal<br>**Phone**: 303-384-6486<br>**Fax**: 303-384-6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>Global Solar Energy, LLC |
| | **DOE Funding Allocation:**<br>1998: $503,263 | **Cost Share Funding:**<br>1998: $115,815 |

**Project Objective:**
The objectives of this research and development include optimization of a continuous roll-to-roll CIGS deposition process, development and optimization of novel scribe and interconnect processes for module formation, and viable encapsulation and finishing methods to produce flexible and rigid mounted PV products.

**Approach/Background:**
GSE has developed the technology to deposit and monolithically integrate CIGS photovoltaics on a flexible substrate. In the GSE approach, long (up to 700 m) continuous rolls of substrate are processed as opposed to individual small glass plates. In combination with roll-to-roll processing, GSE has developed sputtering and evaporation deposition operations that enable low cost and high efficiency CIGS modules.

**Status/Accomplishments:**
A state of the art building dedicated to manufacturing CIGS has been completed in Tucson, AZ. Manufacturing equipment designed to provide a 1.5 MW/year production capability has been installed and qualified. Device efficiencies ~ 10% have been measured for roll-coated CIGS films. The various thin film deposition, monolithic integration, and encapsulation steps are currently being integrated for module fabrication.

**Planned FY 1999 Milestones:** Fabricate an approximately 1000 $cm^2$ flexible thin-film CIGS module with aperture area efficiency greater than 7%. All thin films will be deposited using a continuous roll-to-roll process.

**Major Articles Published in FY 1998:**
S. Wiedeman, R.G. Wendt, J.S. Britt, "Module Interconnects on Flexible Substrates", *NCPV Program Review Meeting; Proceedings of the 15th Conference, Denver, CO, 1998*; AIP Conference Proceedings (in press).

## Thin-Film Technologies

# Optimization of Transparent and Reflecting Electrodes for Amorphous Silicon Solar Cells

| **Contract #:** XAN-4-13318-05 | **Contract Period:** 5/17/94–5/01/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Presidents and Fellows of Harvard College<br>Cambridge, MA 02138- | |
| | **Organization Type**: CU | **Congressional District:** 10 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R.G. Gordon<br>**Phone:** 617-495-4017 **Fax:** 617-495-4723 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1994: $73,000 — 1997: $114,181<br>1995: $163,810 — 1998: $39,500<br>1996: $142,251 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States ensuring that this industry remains a world leader in the a-Si technology; help the U.S. amorphous silicon PV industry to achieve the U.S./DOE PV Program FY 1995 milestone of 10% stable efficiency commercial thin-film modules; help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background**: Develop transparent electrodes for amorphous silicon solar cells using atmospheric pressure chemical vapor deposition techniques.

**Status/Accomplishments:** Developed a new non-pyrophoric precursor for the CVD deposition of ZnO. Many new transparent contact and "backreflector" layers were evaluated in collaboration with the a-Si Device Design Team.

**Planned FY 1999 Milestones:** None; project completed.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Report; NREL/SR-520-25424 (9/98).

**Major Articles Published in FY 1998:**
None.

## Thin-Film Technologies

# Optimization of Transparent and Reflecting Electrodes for Solar Cells

| **Contract #:** XAK-8-17619-26 | **Contract Period:** 4/15/98–11/15/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | President and Fellows of Harvard College<br>Office of Sponsored Research<br>Holyoke Center 440<br>Cambridge, MA 02138 | |
| | **Organization Type**: CU | **Congressional District:** 10 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>R. Gordon<br>**Phone:** 617-495-4017 **Fax:** 617-495-4723 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $86,000 | **Cost Share Funding:** |

**Project Objective:** The objectives of the program are to develop new higher performance, lower cost transparent conductor layers and diffusion barriers for thin-film solar cells, and to work with manufacturers to scale up their deposition processes for commercial production.

**Approach/Background:** Atmospheric pressure chemical vapor deposition (APCVD) is a cost-effective process already being used in the production of transparent conductive oxide (TCO) layers in thin-film solar cells. Higher optical transparency and lower electrical resistance of these layers will lead to higher efficiency cells. Diffusion barriers between soda-lime glass and the TCO may also lower its electrical resistance. Efficiency may also be increased by placing buffer layers with high electrical resistance between the TCO and the absorbing layers of a cell.

**Status/Accomplishments:**
Tested chemical precursors for zinc and tin for compatibility in a potential APCVD process for zinc stannate.
Improved control over the roughness of fluorine-doped zinc oxide (ZnO:F) surfaces for enhanced light-trapping in amorphous silicon cells.
Increased the electrical conductivity of the TCO ZnO:F by placing an amorphous aluminum oxide layer between the ZnO:F and its soda-lime glass substrate.

**Planned FY 1999 Milestones:**
Develop a process for APCVD of zinc stannate films.
Optimize the efficiency of amorphous silicon solar cells based on an APCVD process for transparent conducting fluorine-doped zinc oxide.
Optimize an APCVD process for amorphous aluminum oxide for use as a diffusion barrier on soda-lime glass.
Develop an APCVD process for high-resistance tin oxide.

**Major Reports Published in FY 1998:** None (new subcontract).

**Major Article Published in FY 1998:**
Chen, Feng; DiCeglie, Jr., Nicholas J.; Kenigsberg, Amos; Liu, Xinye; Teff, Daniel J.; Thornton, John; Gordon, Roy G., New Liquid Precursors for Chemical Vapor Deposition, Mater. Res. Soc. Symp. Proc. **495**, 63-68 (1998).

## Thin-Film Technologies

# Optimization of Processing and Modeling Issues for Thin Film Solar Cells

| **Contract#:** ZAK-8-17619-33 | **Contract Period:** 8/24/98–10/23/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King, **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer, **Phone:** 202-586-2455, **Fax:** 202-586-8148 | Institute of Energy Conversion<br>University of Delaware<br>Newark, DE 19716 | |
| | **Organization Type:** CU | **Congressional District:** AL |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>R. W. Birkmire<br>**Phone:** 302-831-6220 **Fax:** 302-831-6226 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** 303-384-6480<br>**Fax:** 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>Institute of Energy Conversion |
| | **DOE Funding Allocation:**<br>1998: $150,000 | **Cost Share Funding:**<br>1998: $31,579 |

**Project Objective:** The overall goals are to develop the science and engineering basis needed to: 1) effectively transfer laboratory results to first time manufacturing, and 2) advance performance and manufacturability of thin film solar cells made from Cu(InGa)(SeS), CdTe and thin Si materials. The objectives are to develop improved techniques for growth and analysis of semiconductor thin films and devices over large areas at high rates, and to assist industry in transferring laboratory results to economical manufacturing processes while maintaining high efficiencies.

**Approach/Background:** The approach for CIGS is: to develop improved materials with bandgaps from 1.3 t o1.9 eV by alloying with S, and to incorporate these CIGSS alloys in dual bandgap tandem cells; to understand CIGSS limiting reactions from 400 to 600°C; and to identify critical interdependencies between substrate, semiconductor and TCO. The approach for CdTe is: to improve TCO/CdS/CdTe devices with thin CdS layers by altering the TCO or device processing; to perform stability tests on a variety of differently deposited CdTe devices and interpret results in terms of back contact and doping; and to optimize alternate Cl treatments. The approach for thin Si is: to establish how optimized p-layers, including microcrystalline layers, deposited by plasma CVD, affect $V_{oc}$; and to explore the growth of large grain polycrystalline Si thin films by hot wire.

**Status/Accomplishments:** The present contract has been in place for approximately two months. During this time, we have investigated recrystallization of CIGS during growth at 400°C, determined experimentally the diffusion coefficient for S into CdTe, and deposited Si p-layers by plasma CVD having mixed a-SiC and crystalline Si phases with high conductivity (~1 S/cm).

**Planned FY 1999 Milestones:** Establish operation of new "in-line" CIGS system. Develop S-based $CuInGaS_2$ solar cells with bandgaps > 1.5 eV and $V_{oc}$> 0.75 V. Determine if CdTe(S) absorber alloys widen the process window for thin CdS layers. Quantify CdS-CdTe interdiffusion for varying S concentrations, and temperature and time of Cl treatment. Conduct controlled stress studies on partially completed CdTe devices to determine effect of contact on stability. Develop high conductivity, high transparency µc-Si alloy p-layers. Fabricate back reflector structures for analysis by other a-Si team members to understand optical enhancement. Support national Thin Film Partnership Teams in all programs.

**Major Reports Published in FY 1998:** Since the contract is less than three months we have not published a quarterly report.

**Major Articles Published in FY 1998:**

R. Birkmire and M. Engelmann, "Chemical Kinetics and Equilibrium Analysis of I-III-VI Films," *Proceedings of the 15th NCPV Program Review Meeting, Denver, CO, 1998;* AIP Conference Proceedings (in press).

E. Eser, S.S. Hegedus and W.A. Buchanan, "Preparation and Characterization of Micro-Crystalline Hydrogenated Silicon Carbide p-Layers," *Proceedings of the 15th NCPV Program Review Meeting, Denver, CO, 1998;* AIP Conference Proceedings (in press).

B.E. McCandless and R.W. Birkmire, "Influence of Processing Conditions on Performance and Stability in Polycrystalline Thin-Film CdTe-Based Solar Cells," *Proceedings of the 15th NCPV Program Review Meeting, Denver, CO, 1998;* AIP Conference Proceedings (in press).

J.E. Phillips and W.N. Shafarman, "Analysis of $Cu(In,Ga)Se_2$ Solar Cells: Why Performance Decreases with Increasing Ga Content," *Proceedings of the 15th NCPV Program Review Meeting, Denver, CO, 1998;* AIP Conference Proceedings (in press).

## Thin-Film Technologies

# Application of CIS to High Efficiency PV Module Fabrication

| **Contract#:** ZAF-5-14142-07 | **Contract Period:** 4/7/95–6/6/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | International Solar Electric Technology Inc. (ISET)<br>8635 Aviation Blvd.<br>Inglewood, CA 90301 | |
| | **Organization Type:** IN | **Congressional District:** 35 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>B. M. Basol, V. K. Kapur<br>**Phone:** 310-216-1422 **Fax:** 310-216-2908 | |
| **Technical Monitor:**<br>H. S. Ullal<br>**Phone:** 303-384-6486<br>**Fax:** 303-384-6430 | **B&R Code:** EB22 | **Cost Share Information:**<br>International Solar Electric Technology Inc. (ISET) |
| | **DOE Funding Allocation:**<br>1995: $ 330,000 — 1997: $536,000<br>1996: $ 495,000 — 1998: $189,000 | **Cost Share Funding:**<br>1995: $ 36,000 — 1997: $ 60,000<br>1996: $ 55,000 — 1998: $ 21,000 |

**Project Objective:** The objectives of this research effort include substrate investigation, Mo contacts, optimization of laser scribing and module integration scheme, and development of a low-cost deposition method for the growth of CIS absorber layers.

**Approach/Background:** The present project aims to develop a novel, low-cost, non-vacuum deposition method for the growth of CIS absorbers for solar cell applications. The technique utilizes low cost equipment to process large area substrates. It has excellent control on the composition of the depositing species and has very high materials utilization.

**Status/Accomplishments:** A simple and low-cost technique has been successfully developed for the deposition of CIS layers. The method utilizes nano-particle technology. First a nano-particle powder is prepared within which the Group I/Group III stoichiometric ratio is fixed. Then an ink is prepared using this nano-particle powder. The ink is then deposited on the selected substrate using a simple technique such as spraying, screen printing or doctor blading. The precursor layer thus prepared is later converted into the desired chalcopyrite film. Small area solar cells with 12.4% total area efficiency and submodules with over 8% efficiency have been demonstrated using this technique. A facility is being set up to process 13”x13” size modules.

**Major Reports Published in FY 1998:**

*NREL Photovoltaic Program FY 1997 Annual Report,* NREL/BK-210-23607, (June 1998).

B.M. Basol et al., *Final Technical Report, June 1998* (in press).

**Major Articles Published in FY 1998:**

C.R. Leidholm, et al., *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Thin-Film Technologies

# CIS-Type PV Device Fabrication by Novel Techniques

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| **Contract#:** ZAK-8-17619-10 | **Contract Period:** 6/30/98–6/29/01 |
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| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King, **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer, **Phone:** 202-586-2455, **Fax:** 202-586-8148 | International Solar Electric Technology Inc. (ISET)<br>8635 Aviation Blvd.<br>Inglewood, CA 90301 | |
| | **Organization Type:** IN | **Congressional District:** 35 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>B. M. Basol, V. K. Kapur<br>**Phone:** 310-216-1422 **Fax:** 310-216-2908 | |
| **Technical Monitor:**<br>H. S. Ullal<br>**Phone:** 303-384-6486<br>**Fax:** 303-384-6430 | **B&R Code:** EB22 | **Cost Share Information:**<br>International Solar Electric Technology Inc. (ISET) |
| | **DOE Funding Allocation:**<br>1998: $350,000 | **Cost Share Funding:**<br>1998: $37,168 |

**Project Objective:** The objectives of this research effort include investigation of a new contact material replacing Mo, novel integration schemes for module manufacturing, device stability evaluation, bandgap engineering approaches, and preparation of larger bandgap chalcopyrite films using a low-cost, non-vacuum technique. Work will also be carried out on the development of buffer layers replacing CdS

**Approach/Background:** The most important goal of the present project is the preparation of larger bandgap chalcopyrite thin films using a novel, low-cost, non-vacuum deposition method. The technique utilizes nano-particle technology. First a nano-particle powder is prepared within which the Group I/Group III stoichiometric ratio is fixed. Then an ink is prepared using this nano-particle powder. The ink is then deposited on the selected substrate using a simple technique such as spraying, screen printing or doctor blading. The precursor layer thus prepared is later converted into the desired chalcopyrite film. The method has already been demonstrated for the growth of high quality CIS layers. The aim in this program is to apply this technique to the growth of larger bandgap materials.

**Status/Accomplishments:** Work is in progress to include S in the absorber layers. Devices have been fabricated on CISS films. Open circuit voltages as high as 0.7 V have been observed. The highest solar cell efficiency obtained is around 12.5%.

**Planned FY 1999 Milestones:** 12% large bandgap CIS-based cells, 9% modules by novel technique.

**Major Reports Published in FY 1998:**
None.

**Major Articles Published in FY 1998:**
None.

## Thin-Film Technologies

# Comprehensive Research on Stability and Performance on a-Si:H and Alloys

| **Contract #:** XAN-4-13318-08 | **Contract Period:** 5/31/94–7/15/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Iowa State University<br>Ames, IA 50011- | |
| | **Organization Type**: CU | **Congressional District:** 3 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>V.L. Dalal<br>**Phone:** 515-294-1077 **Fax:** 515-294-9584 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $140,900 — 1997: $247,084<br>1995: $355,981 — 1998: $65,012<br>1996: $309,907 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States ensuring that this industry remains a world leader in the a-Si technology; help the U.S. amorphous silicon PV industry to achieve the U.S./DOE PV Program FY 1995 milestone of 10% stable efficiency commercial thin-film modules; help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Deposit amorphous silicon and alloys using electron cyclotron microwave enhanced chemical vapor deposition (ECR-CVD)

**Status/Accomplishments:** Fabricated substrate ("n-i-p") devices using ECR-CVD.

**Planned FY 1999 Milestones:** None; project completed.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998). [if appropriate]

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press.

## Thin-Film Technologies

# Research on Improved Amorphous Silicon and Alloy Materials and Devices Prepared using ECR Plasma Techniques

| **Contract#:**XAF-8-17619-30 | **Contract Period:** 07/01/98–6/30/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Iowa State University<br>Ames, Iowa 50011 | |
| | **Organization Type:** CU | **Congressional District:** 3 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Vikram Dalal<br>**Phone:** 515 294 1077 **Fax**: 515 294 9584 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** 303-384-6480<br>**Fax:** 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1998: $70,000 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States. This will be carried out within the context of the research and development sub-Teams established by the NREL/EPRI Thin Film Partnership. The work is focussed on developing higher, performance, more stable a-Si and a-(Si,Ge)solar cells using innovative plasma deposition technology. Ultimately the goal of the Amorphous Silicon Team is to achieve 15% stable thin-film modules by 2005.

**Approach/Background:** The approach is to use controlled ECR plasma technology to deposit a-Si and a-(Si,Ge) solar cells. In particular, plasma conditions such as radical chemistry and ion bombardment will be varied to study their influence on material and device properties and stability. Both substrate and superstrate type cells will be made.

**Status/Accomplishments:** (1) Using controlled changes in plasma chemistry, it was demonstrated that ion bombardment plays a major role in achieving better films and devices in a-(Si,Ge) alloys; (2) It was found that some of the degradation in the performance of a-Si solar cells was occurring at the p-I interface, and that changing this interface resulted in improved stability of the devices; (3) A lower gap (1.65 eV) a-Si material was made with good electronic properties by using chemical annealing with He.

**Planned FY 1999 Milestones:** (1) Better understanding of differences in a-Si films and devices deposited by He vs. Hydrogen ECR process; (2) Determination of device properties using combination of He and Hydrogen ECR plasma; (3) Comprehensive characterization of ECR deposited materials and devices by collaboration with other team members

**Major Reports Published in FY 1998:** *none due*

**Major Articles Published in FY 1998:**

NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998; AIP Conference Proceedings (in press)
Proceedings of Materials Research Society, Spring meeting, (San Francisco, 1998)
Proceedings of 2nd. World Photovoltaic Energy Conference, (Vienna, July 1998)
*J. Non-crystalline Solids*, Vol. 227-230 (1998)

# Atmospheric Pressure Chemical Vapor Deposition of CdTe for High Efficiency Thin Film PV Devices

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| **Contract#:** ZAK-8-17619-03 | **Contract Period:** 1/26/98–1/25/01 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King, **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer, **Phone:** 202-586-2455, **Fax:** 202-586-8148 | ITN Energy Systems, Inc.<br>12401 West 49th Ave.<br>Wheat Ridge, CO 80033 | |
| | **Organization Type:** IN | **Congressional District:** 2 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>P.V. Meyers<br>**Phone:** 303 420-1141 **Fax:** 303-420-1551 | |
| **Technical Monitor:**<br>H.S. Ullal<br>**Phone:** 303 384-6486<br>**Fax:** 303 384-6430 | **B&R Code:** EB22 | **Cost Share Information:**<br>ITN Energy Systems, Inc. |
| | **DOE Funding Allocation:**<br>1998: $198,310 | **Cost Share Funding:**<br>1998: $28,033 |

**Project Objective:** Overall objective is improved thin film CdTe PV manufacturing technology using atmospheric pressure chemical vapor deposition method, with increased power conversion efficiency. Tasks required to accomplish the overall goal are grouped into 1) development of deposition apparatus and procedures which enable control of film growth over large area and 2) development of advanced measurement and analytical procedures which provide useful and effective device characterization.

**Approach/Background:** CdTe deposition by Atmospheric Pressure Chemical Vapor Deposition (APCVD) employs the same reaction chemistry as has been used to deposit 16% efficient CdTe PV films (Close Spaced Sublimation) but employs forced convection rather than diffusion as a mechanism of mass transport. APCVD enables discovery of fundamental mass transport parameters which, through application of established engineering principles, can be used to design high throughput, high yield manufacturing equipment. Device analysis will go beyond conventional one-dimensional device characterization and analysis toward two dimension measurements and modeling.

**Status/Accomplishments:** During Phase I the APCVD reactor has been designed, all components have been constructed and assembly is nearly complete. Initial device modeling is being performed using AMPS 1-D. Equipment for two-dimensional characterization of films using AC impedance and Near Field Scanning Micro Photoconductivity is in place and initial studies have begun.

**Planned FY 1999 Milestones:**
Demonstration of device quality CdTe films.
Demonstration of 12% total-area conversion efficiency.
Presentation of two-dimensional methods for characterization and analysis of device operation on a microscopic scale.

**Major Reports Published in FY 1998:**
None.

**Major Articles Published in FY 1998:**
*P. Meyers, R. Kee, L. Raja, C. Wolden and M. Aire, "Atmospheric Pressure Chemical Vapor Deposition of CdTe–Reactor Design Considerations", NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

## Thin-Film Techologies

# In-Situ Sensors for Process Control of $CuInGaSe_2$

| **Contract #:** ZAK-8-17619-08 | **Contract Period:** 2/10/98–2/09/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Materials Research Group, Inc.<br>12441 W. 49th Ave., Suite #2<br>Wheat Ridge, CO 80033-1927 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>I.L. Eisgruber<br>**Phone:** 303-425-6688 x 15 **Fax:** 303-425-6562 | |
| **Technical Monitor:**<br>H.S. Ullal<br>**Phone**: 303-384-6486<br>**Fax**: 303-384-6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>Materials Research Group, Inc. |
| | **DOE Funding Allocation:**<br>1998: $90,000 | **Cost Share Funding:**<br>1998: $10,000 |

**Project Objective:**
Yield and reproducibility issues must be resolved for thin-film $CuInGaSe_2$ modules to be manufactured profitably. The purpose of this subcontract is to develop in-situ sensors to improve yield, reproducibility, and efficiency of thin-film $CuInGaSe_2$ modules.

**Approach/Background:**
In-situ x-ray fluorescence is being used to monitor composition and thickness of deposited layers, and in-situ optical emission spectroscopy will be used to provide real-time feedback describing the deposition plasma. Characterization techniques will be examined ex-situ for the initial part of the subcontract, and applied to existing deposition systems in the final year of the subcontract.

**Status/Accomplishments:**
The composition of the $CuInGaSe_2$ absorber layer is the most critical and sensitive for device performance. Thus, x-ray fluorescence signals from $CuInGaSe_2$ films and their precursor layers are currently being analyzed.

**Planned FY 1999 Milestones:**
In FY 1999, a summary of the relationships between x-ray fluorescence signals and $CuIn(Ga)Se_2$ film thickness and composition will be reported.

**Major Reports Published in FY 1998:**
None.

**Major Articles Published in FY 1998:**
I.L. Eisgruber, T. Wangensteen, C. Marshall, B. Carpenter, "X-Ray Fluorescence as an In-Situ Composition Monitor During $CuIn_xGa_{1-x}Se_2$ Deposition", *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

# High Efficiency, Stable Hot Wire CVD Prepared Amorphous and Polycrystalline Silicon Film Solar Cells

| **Contract #:** ZAK-8-17619-16 | **Contract Period:** 4/10/98–4/9/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | MVSystems, Inc.<br>17301 West Colfax Avenue, Unit 305<br>Golden, CO 80401 | |
| | **Organization Type**: IN | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Arun Madan<br>**Phone:** 303-271-9907 **Fax:** 303-271-9771 | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone**: 303-384-6441<br>**Fax**: 303-384-6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>MVSystems Inc. |
| | **DOE Funding Allocation:**<br>1998: $175,000 | **Cost Share Funding:**<br>1998: $20,000 |

**Project Objective:**
The objective of this R&D contract is to develop a high quality amorphous (a-) and micro-crystalline (μc-) Si-based thin film alloy materials by Hot Wire Chemical Vapor Deposition and use these materials to fabricate high efficiency PV devices. The goal at the end of the three year program is to demonstrate and deliver 12% stable a-Si-based devices and 10% μc-Si based devices.

**Approach/Background:**
Hot Wire Chemical Vapor Deposition (HWCVD) is important because silicon films can be produced as either amorphous or polycrystalline depending on process conditions; and the amorphous films have exhibited superior stability compared to PECVD films. A-Si:H solar cells with improved stability have been demonstrated by HWCVD, albeit at lower performance value in comparison with the PECVD approach. Micro-crystalline silicon (μc-Si) thin films in a solar cells configuration of moderate efficiency have been reported recently. MVS intends to explore the potential of the HWCVD deposition approach for both a-Si and μc-Si materials and their use in thin film silicon PV devices.

**Status/Accomplishments:**
The project was started on April 10, 1998. The following has been accomplished: 1. completed the upgrade of a single chamber with the capability of PECVD and HWCVD deposition techniques. An innovative new HWCVD technique has been successfully incorporated into the system which has produced high quality a-Si materials and "base-line" μc-Si materials. Also, we have demonstrated a "base-line" Schottky barrier PV device. Further, we have nearly completed the following processing and characterization equipment for supporting the material and device research: solar simulator alloying light and dark J-V measurements, temperature-dependent conductivity measurement, thermal evaporator, and a RF magnetron sputtering system.

**Planned FY 1999 Milestones:**
1. Finalize device structure and deposition techniques for fabricating the devices.
2. Finalize the HWCVD-PECVD system configuration.
3. Demonstrate an 8% stabilized efficiency device using a combination of deposition techniques (HWCVD-PECVD) and a combination of μc-Si and a-Si materials.

**Major Reports Published in FY 1998:**
None.

**Major Articles Published in FY 1998:**
*Deposition of High Quality a-Si Films by An Innovative "Hot Wire" CVD Technique, NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Characterization of Small Particle Formation in the Preparation of Amorphous Silicon Solar Cells and Determination of the Electric Field Profile in Solar Cells using Scanning Tunneling Microscopy

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| **Contract#:** DAD-8-18653-01 | **Contract Period:** 07/01/98-06/30/01 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King J. Mazer<br>**Phone:** 202-586-1693 **Phone:** 202-586-2455<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | National Institute of Standards and Technology<br>Boulder, CO, 80309-0440 | |
| | **Organization Type:** CU | **Congressional District:** 4 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Alan C. Gallagher<br>**Phone:** 303-497-3936 **Fax:** 303-492-5235 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** 303-384-6480<br>**Fax:** 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1998: $60,000 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States. This will carried out within the context of two of the research and developments sub-Teams established by the NREL/EPRI Thin Film Partnership. Project Objective: This work will (1) support the National Amorphous Silicon Team with expertise relating to film growth phenomena and nano-size particle formation during deposition of a-Si:H films, and (2) employ a new scanning tunneling microscope (STM) spectroscopic technique to measure the electric field profile in thin-film solar cells. Ultimately the goal of the Amorphous Silicon Team is to achieve 15% stable thin-film modules by 2005.

**Approach/Background:** Silicon particles inadvertently form within discharges, and deposit into growing a-Si:H films. Measure particle size and density within the discharge and on the substrate, and use this data to model particle growth and escape to the film. The losses in cells occur within many layers and interfaces, and are hard to measure individually. We will measure the apparent potential (AP) versus depth within a cleaved single, tandem and triple cell made from a-Si:H and its alloys.

**Status/Accomplishments:** We have measured particle densities and growth rates within 300 K silane discharges. We have developed a complete plasma-chemistry model for this growth process. We have measured the AP of a single and tandem cell, for one region of a cleaved surface.

**Planned FY 1999 Milestones:** Measure particle growth in silane/hydrogen mixtures and at elevated temperatures. Develop a quantitative model for the relationship of the AP and the STM current-voltage relation to the local carrier densities and quasi Fermi levels within the operating cell.

**Major Reports Published in FY 1998:** *none due*

**Major Articles Published in FY 1998:** none

## Thin-Film Technologies

# Stable a-Si:H Based Multijunction Solar Cells with Guidance from Real Time Optics

| **Contract#:** XAF-8-17619-22 | **Contract Period:** 3/15/98–9/16/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | The Pennsylvania State University<br>University Park, PA 16802 | |
| | **Organization Type:** CU | **Congressional District:** 5 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Christopher R. Wronski<br>**Phone:** 814-865-0930 **Fax:** 814-863-5341 | Robert W. Collins<br>**Phone:** 814-865-3059 **Fax:** 814-865-2326 |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** 303-384-6480<br>**Fax:** 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1998: $175,000 | **Cost Share Funding:** |

**Project Objective:**
The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States and help the U.S. amorphous silicon PV industry to be competetive by enhacing perormance and cost-efficiency, e.g., by using higher deposition rates. An important aspect is to improve the understanding of the details of all mechanisms limiting device performance. The advantages of using new materials preparation schemes, material and device characterization schemes, and device modeling schemes will be documented.

**Approach/Background:**
Develop processing schemes for fabrication of high performance, stable a-Si:H based multijunction solar cells with guidance from real time optics and detailed characterization of materials and device structures.

**Status/Accomplishments:**
Using real time optics characterized the growth, microstructure and amorphous/microcrystalline phase boundaries in protocrystalline thin film materials. Utilized protocrystalline using spectroscopic ellipsometry materials in stable a-Si:H solar cells including 1900 Å cells with fill factors of 0.7–0.7 in the AM 1.5 degraded steady state developed detailed optical and structural characterizations of textured TCO substrates suitable for in situ studies on the growth of solar cells on such substrates. The only US amorphous silicon group invited by NEDO/PVTEC to participate in their 1998 international collaborative program.

**Planned FY 1999 Milestones:**
Develop novel higher stability, efficient solar cell structures based materials at the amorphous side of the boundary between the amorphous and microcrystalline structure.

**Major Reports Published in FY 1998:** none yet, new subcontract.

**Major Articles Published in FY 1998:**
*Proceedings of the 1998 Spring Meeting of the Materials Research Society,* San Francisco, CA , (4/98), two articles.
*Proceedings of 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion,* Vienna, Austria, (July 6-10, 1998), two articles.
*Applied Physics Letters,* two articles.
*Journal of Applied Physics,* one article.
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## Thin-Film Technologies

# Wide-Band-Gap Solar Cells with High Stabilized Performance

| **Contract#:** XAN-4-13318-03 | **Contract Period:** 7/13/94–3/15/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | The Pennsylvania State University<br>University Park, PA 16802 | |
| | **Organization Type:** CU | **Congressional District:** 5 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Christopher R. Wronski — **Phone:** 814-865-0930 — **Fax:** 814-863-5341<br>Robert W. Collins — **Phone:** 814-865-3059 — **Fax:** 814-865-2326 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** 303-384-6480<br>**Fax:** 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1994: $125,000 — 1997: $163,791<br>1995: $256,275 — 1998: $ 65,000<br>1996: $207,921 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States; help the U.S. amorphous silicon PV industry to achieve the U.S./DOE PV Program FY 1995 milestone of 10% stable efficiency commercial thin-film modules; and help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Characterize growth of amorphous silicon-based solar cells using spectral ellipsometry and optimize device design.

**Status/Accomplishments:** Achieved state-of-the-art diagnostic solar cells with high (>950 mV) open-circuit voltage using "hydrogen dilution" deposition schemes in super and substrate cell configurations. Only U.S. amorphous silicon group invited to participate in the Japanese "Sunshine" Workshops. Evaluated a new proposed distribution of dangling bond states in amorphous silicon.

**Planned FY 1999 Milestones:** FY 1998: New subcontract. Deposit and characterize thin nano and microcrystalline silicon layers.

**Major Reports Published in FY 1998:** *Final Subcontract Report,* NREL/SR-520-25271 (8/98)

**Major Articles Published in FY 1998:**
*Proceedings of the 26th IEEE PV Specialists Conference,* Anaheim, CA (9/29-10/3/97), four articles.
*Proceedings of the Fall MRS Meeting,* Boston, MA (12/97), two articles.
*Technical Digest of the 11th Sunshine Workshop,* Tokyo, Japan, (1/98), two articles.

## Thin-Film Technologies

# CIS-Based Thin-Film PV Technology

| **Contract #:** ZAF-5-14142-03 | **Contract Period:** 8/23/95–12/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Siemens Solar Industries<br>4650 Adohr Lane<br>Camarillo, CA 93010 | |
| | **Organization Type:** IN | **Congressional District:** 23 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Dale E. Tarrant<br>**Phone:** 805-388-6328 **Fax:** 805-388-6580 | |
| **Technical Monitor:**<br>H.S. Ullal<br>**Phone:** 303-384-6486<br>**Fax:** 303-384-6430 | **B&R Code:** EB22 | **Cost Share Information:**<br>Siemens Solar Industries |
| | **DOE Funding Allocation:**<br>1996: $885,077 1997: $1,038,567<br>1998: $1,076,373 | **Cost Share Funding:**<br>1996: $885,077 1997: $1,038,567<br>1998: $1,076,373 |

**Project Objective:** The primary objective is to establish reliable high-throughput, high-yield thin film deposition processes that utilize large-scale processing equipment largely developed for existing non-PV industrial thin-film production in order to make CIS a viable option for the next generation of photovoltaics.

**Approach/Background:** Statistical Process Control is used to refine baseline processes for higher efficiency, higher yield, and to rigorously demonstrate baseline process reproducibility thereby demonstrating the foundations for process scale-up. The primary subcontract goals are to deliver a champion 13% efficient large area module and sets of modules in 1-kW arrays of steadily increasing efficiency reaching 12% by the end of the third year. During the subcontract period, SSI delivered a set of $Cu(In,Ga)(S,Se)_2$ modules to NREL for a 1 kW array replacing an existing array based on $Cu(In,Ga)Se_2$. NREL confirmed a world-record 11.1%, 3665 $cm^2$ aperture area efficiency. Based on advances in understanding regarding the influence of reactor design on performance, SSI designed and built a new large-area reactor which is a more direct scale-up of the baseline reactor.

**Status/Accomplishments:** Subcontract work included demonstrating process capability in the new large area reactor and developing module processes to pass accelerated environmental tests. Impacts on accelerated testing were demonstrated for exposure to humidity during circuit plate processing, and for various materials and procedures for encapsulation. Substrate size was scaled from 1x1 ft. to 1x4 ft. in the new large area reactor. Low capacity production of prototype 1x4 ft. circuit plates was accomplished applying statistical Process Control and Analysis of Variation methodologies to develop a low variation process through repeated "cycles of learning." SSI delivered 32 1x4 ft. modules, ~1.2 kW to upgrade the test array at NREL. The NREL measured average efficiency at standard test conditions of 11.4 % is the highest array efficiency for any thin-film technology. NREL confirmed a world-record 11.8 %, 3651 $cm^2$ aperture area efficiency for the champion module. The efficiency of all modules far exceeds the DOE year 2000 goal of 10% for commercial CIS modules.

**Planned FY 1999 Milestones:** Install a 1-kW CIGSS array with system efficiency of about 10% at NREL's OTF.

**Major Reports Published in FY 1998:**

D. Tarrant, R. Gay, "Thin-Film Photovoltaic Partnership Program–CIS-based thin film PV Technology. Phase 2 Technical Report, October 1996-October 1997," (May 1998) NREL report NREL/SR-520-24751.

**Major Articles Published in FY 1998:**

R. D. Wieting, "CIS Product Introduction: Progress and Challenges", National Center for Photovoltaics Program Review Meeting, Denver, Colorado, September 9, 1998, to be published in AIP Conference Proceedings.

# Technology Support for Initiation of High-Throughput Processing of Thin-Film CdTe PV Modules

| **Contract #:** ZAF-5-14142-05 | **Contract Period:** 3/14/95–3/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Solar Cells, Inc.<br>1702 N. Westwood Ave.<br>Toledo, OH 43607 | |
| | **Organization Type**: IN | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>G.L. Dorer and R.C. Powell<br>**Phone:** 419-872-7661 **Fax:** 419-872-7665 | |
| **Technical Monitor:**<br>H.S. Ullal<br>**Phone**: 303-384-6486<br>**Fax**: 303-384-6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solar Cells, Inc. |
| | **DOE Funding Allocation:**<br>1996: $898,179 1997: $986,085<br>1998: $1,032,511 | **Cost Share Funding:**<br>1996: $180,000 1997: $200,000<br>1998: $258,128 |

**Project Objective:**
The project objective is to develop equipment and processes for very large-scale production of high-efficiency CdTe/CdS thin-film photovoltaics. This subcontract focussed on development of high-rate semiconductor deposition, all-dry device processing, and testing of long-term stability.

**Approach/Background:**
Cost-effective PV electrical generation requires rapid and robust production, high efficiency, and stable long-term performance. SCI's approach has been to develop a commercial high-speed semiconductor coating process, improve efficiency by reducing optical losses, simplify processing through the use of all-dry processing, and verify stable module performance through accelerated life testing and outdoor array monitoring.

**Status/Accomplishments:**
SCI believes that a breakthrough in semiconductor deposition was verified in this subcontract period. The new coating method termed Vapor Transport Deposition (VTD) was successfully introduced into pilot production. VTD is a moderate-vacuum, high-temperature coating technology. The VTD process appears to be commercially viable combining continuous material supply, very high deposition rates, high material utilization, good control, durable components, and produces quality films. SCI has also demonstrated a 14.1% small area cell made using scaleable processes. Furthermore, accelerated life testing continues to indicate field-deployed modules are stable, but even more robust structures are possible.

**Planned FY 1999 Milestones:**
None.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
2 patent applications for VTD technology.

# Technology Support for Initiation of High-Throughput Processing of Thin-Film CdTe PV Modules

| **Contract #:** ZAK-8-17619-17 | **Contract Period:** 4/1/98–3/31/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Solar Cells, Inc.<br>1702 N. Westwood Ave.<br>Toledo, OH 43607 | |
| | **Organization Type**: IN | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>G.L. Dorer and R.C. Powell<br>**Phone:** 419-872-7661 **Fax:** 419-872-7665 | |
| **Technical Monitor:**<br>H.S. Ullal<br>**Phone**: 303-384-6486<br>**Fax**: 303-384-6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solar Cells, Inc. |
| | **DOE Funding Allocation:**<br>1998: $460,000 | **Cost Share Funding:**<br>1998: $92,000 |

**Project Objective:**
The project objective is to develop equipment and processes for very large-scale production of high-efficiency CdTe/CdS thin-film modules. This subcontract focuses on development of high-rate semiconductor deposition, all-dry device processing, and testing of long-term stability of large-area modules.

**Approach/Background:**
Cost-effective PV electrical generation requires rapid and robust production, high efficiency, and stable long-term performance. SCI approach is to continue development of its proprietary VTD semiconductor coating process; complete laboratory testing of 2 promising process improvements prior to scale-up; and continue verification of stable module performance through accelerated life testing and outdoor array monitoring. Studies of the mechanisms of stress-induced change are now being emphasized.

**Status/Accomplishments:**
The proprietary breakthrough VTD semiconductor-coating process developed in the previous subcontract excelled during the rigors of continued pilot production. Fine-tuning of the method continued, as well as design for a production machine with a doubled web width (4 ft). Laboratory testing of 2 all-dry process improvements was successful and indicated scale-up should proceed. Design and construction of the needed equipment commenced. Both of these process improvements will result in process simplification. Accelerated life testing continues to indicate field-deployed products are stable, but even more robust structures are possible.

**Planned FY 1999 Milestones:**
FY1999: Implement the VTD coating system in a new production machine with the capability of deposition onto a 4 ft wide web. Scale two all-dry processes and incorporate into pilot production. Fabricate 10%-efficient thin-film CdTe module.

**Major Reports Published in FY 1998:**
None.

**Major Articles Published in FY 1998:** R.C. Powell, U. Jayamaha, G.L. Dorer, H. McMaster, "Scaling and Qualifying CdTe/CdS Module Production", in *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

## Thin-Film Technologies

# Amorphous Silicon Research

| **Contract #:** ZAN-4-13318-01 | **Contract Period:** 9/13/94–2/28/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Solarex, A Business Unit of Amoco/Enron-<br>826 Newtown-Yardley Road<br>Newtown, PA 18940 | |
| | **Organization Type**: IN | **Congressional District:** 8 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. Arya<br>**Phone:** 215-860-0902 **Fax:** | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone**: 303-384-6441<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solarex |
| | **DOE Funding Allocation:**<br>1995: $400,000 — 1997: $395,494<br>1996: $402,000 — 1998: $39,400 | **Cost Share Funding:**<br>1995: $625,000 — 1997: $395,494<br>1996: $402,000 — 1998: $39,400 |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States; help the U.S. a-Si:H PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

Approach/Background: mprove throughput by 20% over baseline and decrease silicon alloy feedstock by 20% without loss in stabilized module performance. Demonstrate 1 ft2 a-Si modules of at least 9% efficiency for a run of 18 modules with over 75% yield.

**Status/Accomplishments:** The 10-MW a-Si production facility (TF1) in Toano, VA, reached operational status in 1998. Produced large-area (8.6 sq. ft). tandem modules with stabilized output power in the range of 45 to 50 W.

**Planned FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Report, NREL/SR-520-24854, (May 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).
D.E. Carlson and K. Rajan, Applied Physics Letters, 70, [16] 2168-2170 (1997).
D.E. Carlson and K. Rajan, 14th European PV Solar Energy Conf., Barcelona, Spain, 30 June-4 July 1997.
H. Forest, 14th European PV Solar Energy Conf., Barcelona, Spain, 30 June-4 July 1997.

## Thin-Film Technologies

# Research on Amorphous Silicon Cells and Modules

| **Contract #:** ZAK-8-17619-02 | **Contract Period:** 3/9/98–5/8/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Solarex, a Business Unit of Amoco/Enron Solar<br>3601 LaGrange Parkway<br>Toano, VA 23168 | |
| | **Organization Type**: IN | **Congressional District:** 1 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. Arya<br>**Phone:** 757-566-8770 **Fax:** 757-566-8779 | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone**: 303- 384-6441<br>**Fax**: 303-384-6430 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solarex |
| | **DOE Funding Allocation:**<br>1998: $655,019 | **Cost Share Funding:**<br>1998: $760,700 |

**Project Objective:** The overall objective of this project is to develop high performance, large-area, amorphous silicon tandem modules on glass substrates. In Phase I, Solarex has the objective of demonstrating a stabilized conversion efficiency of 10% in 1 $ft^2$ tandem modules and increasing this stabilized efficiency to 11% in Phase II and 12% in Phase III. Another major objective is to demonstrate a stabilized aperture area efficiency of 9.5% in 8 $ft^2$ tandem modules in Phase III.

**Approach/Background:** Solarex plans to investigate several new amorphous silicon deposition modes with the goal of increasing both deposition rate and PV module performance. The new approaches include hot-wire + PECVD, Ar-dilution and He-dilution. Solarex will also be developing new diagnostic characterization tools to assist in the development of high quality amorphous silicon alloys and PV modules. The diagnostic tools under development include laser-defined diodes, in-line PV characterization of partially processed plates, real time spectroscopic ellipsometry (Penn State), optical interference spectroscopy (Univ. of VA), polarization differential reflectance (Univ. of VA) and optical emission spectroscopy.

**Status/Accomplishments:** Initial conversion efficiencies as high as 11.6% have been obtained for small-area tandem cells. Additional processing steps have been developed that lead to improved performance and reduced light-induced degradation. Saturation of the light-induced degradation has been observed in tandem devices both under 1 sun illumination and under accelerated light soaking (60 suns). However, some a-SiGe devices do not show clear evidence of saturation. Both the degradation and annealing kinetics of a-SiGe devices are slower than that observed in a-Si devices. Hydrogen diffusion studies in a-SiGe films indicate that there are two distinct diffusion mechanisms.

**Planned FY 1999 Milestones:** (1) Demonstrate a stabilized conversion efficiency of 10% in a 1 $ft^2$ amorphous silicon tandem module. (2) Demonstrate a stabilized conversion efficiency of 11% in a small-area (~ 0.25 $cm^2$) amorphous silicon tandem cell. (3) Demonstrate an average stabilized efficiency of 9% for 7 out of 10 modules (1 $ft^2$) fabricated on commercial tin oxide coated glass.

**Major Reports Published in FY 1998:**

*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, June 1998.
"Amorphous Silicon Research," Final Technical Report, NREL/SR-520-24854, June 1998.

**Major Articles Published in FY 1998:**

R. R. Arya et al.,"R&D Issues in Scale-Up and Manufacturing of Amorphous Silicon Tandem Modules", *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).
D. E. Carlson and K. Rajan, "Evidence for Proton Motion in the Field-Induced Recovery of Light-Induced Degradation in Amorphous Silicon Solar Cells", J. Appl. Phys. 83 [3] 1726-1729 (1998).
D. E. Carlson, K. Rajan, R. R. Arya, F. Willing and L. Yang, "Advances in Amorphous Silicon Photovoltaic Technology", J. Materials Research 13 [10] (1998).

# Electroabsorption and Transport Measurements and Modeling Research in Amorphous Silicon Based Solar Cells

| **Contract #:** XAK-8-17619-23 | **Contract Period:** 3/24/98–3/23/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Managers:**<br>R. King, **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer, **Phone:** 202-586-2455, **Fax:** 202-586-8148 | Syracuse University<br>Department of Physics<br>Syracuse, NY 13244-1130 | |
| | **Organization Type**: CU | **Congressional District:** 25 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Eric A. Schiff<br>**Phone:** 315-443-3901 **Fax:** 315-443-9103 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $75,000 | **Cost Share Funding:** |

**Project Objective:** The primary objective of this project is to improve the understanding of the factors which limit the open-circuit voltage of amorphous silicon based solar cells; it should be noted that the open-circuit voltages achieved to date are only about 60% of the electrical bandgap in this class of cells. The second objective is to improve the understanding of photocarrier transport in amorphous silicon and related materials.

**Approach/Background:** The experimental approach to understanding open-circuit voltages will emphasize built-in potential ($V_{bi}$) estimates using electroabsorption techniques. In conjunction with this experimental work a program of computer modeling emphasizing the open-circuit voltage will be carried through, with a particular emphasis on marrying the modeling with the best available parameters from experiments at Syracuse University and elsewhere. Transport measurements will emphasize determination of hole and electron drift-mobilities in advanced materials and devices using the photocarrier time-of-flight technique. Improvements in the technique will be carried through to improve measurement capabilities in solar cells, thus avoiding the ambiguities and inconvenience associated with specially-prepared mobility test structures.

**Status/Accomplishments:** The first estimates for $V_{bi}$ in solar cells incorporating a-SiGe alloys have been made using electroabsorption techniques. The cells are from United Solar Systems Corp.; the estimates for $V_{bi}$ are in the range 1.1–1.2 V, suggesting that it is unlikely that the open-circuit voltage in the cells is limited by $V_{bi}$. The values for $V_{bi}$ are nonetheless significantly smaller than would be inferred from the properties of thin-films samples used as the doped layers. Installation of AMPS 1-D, the computer modeling program developed at Pennsylvania State University, has been completed and modeling studies of $V_{oc}$ are underway. A web-site devoted to AMPS modeling of a-Si:H based cells has been created. Hot-wire specimens have been furnished by the NREL amorphous silicon group for measuring hole mobilities on solar cells with opaque substrates. Electroabsorption spectra have been obtained in a wide range of samples, including detection of a new infrared feature which appears to derive from the *n/i* interface zone of a-Si:H based solar cells.

**Planned FY 1999 Milestones:**
- Measurement and modeling of temperature-dependent open-circuit voltage in a-Si:H cells.
- Development of input shells for AMPS and further development of the web-site supporting AMPS modeling in a-Si:H solar cells.
- Completed measurements and analyses of electroabsorption spectra including estimation of built-in potential and interpretation of the novel infrared feature.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Thin-Film Technologies

# Research on High-Bandgap Materials and Amorphous-Silicon-Based Solar Cells

| **Contract #:** XAN-4-13318-06 | **Contract Period:** 5/11/94–1/15/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 **Fax:** 202-586-8148 | Syracuse University<br>Syracuse, NY 13244-1200- | |
| | **Organization Type**: CU | **Congressional District:** 23 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>E. Schiff<br>**Phone:** 315-443-4908 **Fax:** 315-443-9103 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1994: $58,500 1997: $81,208<br>1995: $103,000 1998: $27,500<br>1996: $000,792 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States ensuring that this industry remains a world leader in the a-Si technology; help the U.S. amorphous silicon PV industry to achieve the U.S./DOE PV Program FY 1995 milestone of 10% stable efficiency commercial thin-film modules; and help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Characterize amorphous silicon materials and devices using time-of-flight and electro-absorption techniques.

**Status/Accomplishments:** Advanced the electro-absorption technique and developed a model for mechanisms limiting the open-circuit voltage in amorphous silicon solar cells, and the Principal Investigator is team leader of national amorphous silicon wide-bandgap team.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Report, to be published

**Major Articles Published in FY 1998:**

## Thin-Film Technologies

# High-Efficiency Triple-Junction Amorphous Silicon Alloy Photovoltaic Technology

| **Contract#:** ZAK-8-17619-09 | **Contract Period:** 03/06/98–3/05/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | United Solar Systems Corp.<br>1100 West Maple Road<br>Troy, MI 48084 | |
| | **Organization Type:** IN | **Congressional District:** 12 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>S. Guha<br>**Phone: 248-362-4170 Fax:** 248-362-4442 | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone:** 303-384-6441<br>**Fax:** 303-384-6430 | **B&R Code:** EB22 | **Cost Share Information:**<br>United Solar Systems Corp. |
| | **DOE Funding Allocation:**<br>1998: $892,000 | **Cost Share Funding:**<br>1998: $892,000 |

**Project Objective:** To obtain high efficiency amorphous silicon (a-Si) alloy multijunction cells and modules with low manufacturing cost and high reliability. The program goal is to obtain 12% stable modules that will qualify IEEE-Std 1262-1995 reliability testing.

**Approach/Background:** Using a spectral-splitting, triple-junction structure, United Solar has achieved world-record stabilized total-area cell and aperture-area module efficiencies of 12.0% and 10.2%, respectively. United Solar is also operating a production line with an annual capacity of 5 MW using the triple-junction approach. We shall further improve efficiency by optimizing the component cells of the triple-junction structure and lower manufacturing cost by depositing the cells at higher rates. We shall also carry out fundamental studies to improve our understanding of a-Si alloy materials and cells.

**Status/Accomplishments:** To lower manufacturing cost, we have used a modified very-high-frequency deposition technique at twice the production line deposition rate and achieved a stabilized top cell performance exceeding the Phase I goal. Modules with an initial aperture-area efficiency of ~12% are being light-soaked at NREL for stability measurements. We have also established important correlation between intermediate range order caused by hydrogen dilution and stability of materials and cells.

**Planned FY 1999 Milestones:** Triple-junction modules with stabilized aperture-area efficiency of 10.5%; triple-junction cells with deposition rates at 3-5 Å/s showing total-area stabilized efficiency of 10.7%.

**Major Reports Published in FY 1998:**
None.

**Major Articles Published in FY 1998:**
*Guha, S., Yang, J., Banerjee, A., and Sugiyama, S. (1998). "Material issues in the commercialization of amorphous silicon alloy thin-film photovoltaic technology." MRS 1998 Spring Meeting Proceedings; April 13-17, 1998, San Francisco, CA.*
*Yang, J., Sugiyama, S., and Guha, S. (1998). "Effect of excitation frequency on the performance of amorphous silicon alloy solar cells," MRS 1998 Spring Meeting Proceedings; April 13-17, 1998, San Francisco, CA.*
*Chen, C.C., Lubianiker, Y., Cohen, J.D., Yang, J., Guha, S., Wickboldt, P., and Paul, W. (1998). "The electronic structure, metastability and transport properties of optimized amorphous silicon-germanium alloys." MRS 1998 Spring Meeting Proceedings; April 13-17, 1998, San Francisco, CA.*
Mahan, A.H., Reedy, Jr., R.C., Iwaniczko, E., Wang, Q., Nelson, B.P., Xu, Y., Gallagher, A.C., Branz, H.M., Crandall, R.S., Yang, J., and Guha, S. (1998). "H out-diffusion and device performance in *n-i-p solar cells utilizing high temperature hot wire a-Si:H i-layers." MRS 1998 Spring Meeting Proceedings; April 13-17, 1998, San Francisco, CA.*
*Yang, J., Banerjee, A., Lord, K., and Guha, S. (1998). "Correlation of component cells with high efficiency amorphous silicon alloy triple-junction solar cells and modules." 2nd World Conference and Exhibition on Photovoltiac Solar Energy Conversion Proceedings; July 6-10, 1998, Vienna, Austria.*
*Guha, S., Yang, J., Banerjee, A., Hoffman, K., and Call, J. (1998). "Manufacturing issues for large volume production of amorphous silicon alloy photovoltaic modules." NCPV Photovoltaics Program Review Proceedings; September 8-11, 1998, Denver, CO.*

## Thin-Film Technologies

# Thin Film Amorphous Silicon Alloy Research Partnership

| **Contract #:** ZAF-5-14142-01 | **Contract Period:** 2/2/95–2/1/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | United Solar Systems Corporation<br>1100 West Maple Road<br>Troy, MI 48084 | |
| | **Organization Type**: IN | **Congressional District:** 12 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>S. Guha, J. Yang<br>**Phone:** 810-362-4170 **Fax:** 810-362-4442 | |
| **Technical Monitor:**<br>K. Zweibel<br>**Phone**: 303-384-6441<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>United Solar Systems Corporation |
| | **DOE Funding Allocation:**<br>1995: $583,000 — 1997: $713,000<br>1996: $526,000 — 1998: $170,771 | **Cost Share Funding:**<br>1995: $583,000 — 1997: $713,000<br>1996: $526,000 — 1998: $170,771 |

**Project Objective:** The objectives of this subcontract are to: support the successful near-term commercialization of U.S. thin-film amorphous silicon modules by addressing technical relevant issues; support mid- and longer-term amorphous silicon research and development needed for future product competitiveness; achieve 12% stable efficiency commercial thin-film modules by 1998; and lay the foundation for achieving 15% stabilized efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Develop high efficiency component cells over large areas to prepare for transition to manufacturing and fabricate cells and submodules demonstrating efficiency and process improvements.

**Status/Accomplishments:** Achieved state-of-the-art top, middle, and bottom component cells with world-record performance. Achieved a world record triple-junction, stable cell efficiency of 12.1%.

**Planned FY 1999 Milestones:** None, contract completed.

**Major Reports Published in FY 1998:** None.
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Technical Progress Report, NREL/SR-520-24723, (May 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

# Photocharge Transport and Recombination Measurements in Amorphous Silicon Films and Solar Cells by Photoconductive Frequency Mixing

| | |
|---|---|
| **Contract #:** XAN-4-13318-10 | **Contract Period:** 5/17/94–4/30-98 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Regents of the University of California<br>405 Hilgard Ave.<br>Los Angeles, CA 90024-1406 | |
| | **Organization Type**: CU | **Congressional District:** 29 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Braunstein, R.<br>**Phone:** 310-825-1841 **Fax:** 310-206-5668 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1994: $30,000 — 1997: $22,500<br>1995: $15,000 — 1998: $7,500<br>1996: $30,000 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States ensuring that this industry remains a world leader in the a-Si technology; help the U.S. amorphous silicon PV industry to achieve the U.S./DOE PV Program FY 1995 milestone of 10% stable efficiency commercial thin-film modules; help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Characterize carrier mobilities and lifetimes in amorphous silicon using the photoconductive frequency photomixing technique.

**Status/Accomplishments:** Carried out a quantitative analysis and determined parameters that characterize electron transport in a fluctuating transport bond.

**Planned FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Report submitted for publication.

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Photocharge Transport and Recombination Measurements in Amorphous Silicon Films and Solar Cells by Photoconductive Frequency Mixing

| **Contract #:** XAK-8-17619-24 | **Contract Period:** 4/20/98–7/05/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Regents of the University of California<br>405 Hilgard Ave.<br>Los Angeles, CA 90024-1406 | |
| | **Organization Type**: CU | **Congressional District:** 29 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Braunstein, R.<br>**Phone:** 310-825-1841 **Fax:** 310-206-5668 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $25,000 | **Cost Share Funding:** |

**Project Objective:**
The first objectives of this project is to directly measure the transport properties of amorphous silicon layers used in solar cells and to improve the understanding how these properties change under light-soaking and as the deposition conditions are altered.

**Approach/Background:**
By employing our well established photomixing technique, analysis of the transport properties of amorphous silicon layers and devices are performed. The deduction of the transport parameters directly from photomixing measurements will be attempted. UCLA will work on improving the theories of transport phenomena in disordered materials. Films of interest to the NREL/EPRI amorphous silicon team will be measured and light-soaked as needed.

**Status/Accomplishments:**
Measurements of the mobility and lifetime in the annealed and in the light-soaked states on a-SiGe:H alloys and microcrystalline silicon have enabled a determination of the range and depth of long range potential fluctuations. Greater light stability was observed in the mixed microcrystalline-amorphous state as well as the microcrystalline state. In addition, transport measurements under hydrostatic pressure were performed on hot-wire a-Si:H revealing pressure dependence of mobility and lifetime in the annealed and the light-soaked states.

**Planned FY 1999 Milestones:**
FY 1998-1999:
Films deposited by ECR remote plasma deposition, hot-wire deposition, and hydrogen diluted rf plasma deposition will be characterized in the annealed and light-soaked states using the photomixing technique. A determination will be made whether the photomixing data can support or reject models for light induced degradation mechanisms; e.g., whether the degradation can be described in terms of hydrogen diffusion or in terms of global network changes in addition to the creation of point defects.

**Major Reports Published in FY 1998:** None, new subcontract

**Major Articles Published in FY 1998:**
*(NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press) Determination of the built-in electric field near contacts to polycrystalline $CoInSe_2$–Probing Local Charge Transport Properties by Photomixing–Yi Tang, Shirung Dong, G.S. Sun, R. Braunstein, B. von Roedern

## Thin-Film Technologies

# Optimization of Processing and Modeling Issues for Thin-Film Solar Cell Devices

| **Contract #:** XAK-7-17609-01 | **Contract Period:** 2/3/97–9/1/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 **Fax:** 202-586-8148 | University of Delaware<br>Newark, DE 19716-3820- | |
| | **Organization Type**: CU | **Congressional District:** AL |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R.W. Birkmire<br>**Phone:** 302-831-6220 **Fax:** 302-831-6226 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1997: $902,500<br>1998: $1,010,490 | **Cost Share Funding:** |

**Project Objective:** Develop the necessary understanding to optimize processing conditions and materials properties to advance the performance of thin film solar cells needed to produce efficient, reliable and low-cost flat-plate PV systems in order to meet the DOE PV Program goal set for the year 2005 of achieving commercial, low-cost, 15% efficient thin-film photovoltaic modules.

**Approach/Background:** Characterize and optimize CdTe and CIS materials and devices; investigate in parallel the effects of different deposition techniques on preparing nominally similar solar cell materials; evaluate innovative materials or device structures for polycrystalline thin-film solar cells; and investigate device issues for a-Si:H-based solar cells.

**Status/Accomplishments:** Team leader for a-Si:H "Device Design Team." Patent issued on reaction scheme to form (Cu(In,Ga)Se2 absorbers for high-efficiency solar cells. IEC is DOE's designated Center for Excellence for Thin-Film Photovoltaics.

**Planned FY 1999 Milestones:** Work scheduled to be carried out was transferred to new subcontract ZAK-8-17619-33.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Phase II Annual Report to be published.

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## Thin-Film Technologies

# Future CIS Manufacturing Technology Development

| **Contract #:** XAK-8-17619 | **Contract Period:** 7/8/98–7/7/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Chemical Engineering Department, University of Florida,<br>P.O. Box 116005<br>Gainesville, FL 32605 | |
| | **Organization Type**: CU | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>T.J. Anderson<br>**Phone:** 352-392-0882 **Fax:** 352-392-9513 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**:303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $105,000 | **Cost Share Funding:** |

**Project Objective:** The objective of this project is to develop improved processing schemes for the fabrication of $CuInSe_2$-based solar cells. Equally important is the advancement of our understanding of the important thermochemical and structural properties of the absorber material, as well as the mechanisms of thin film growth and recrystallization. The objective will be accomplished through innovative material and device preparation methods, modeling of the chemical reaction pathways, comparison of deposition control schemes, and using characterization techniques to correlate film properties and device performance.

**Approach/Background:** A team of researchers from 3 disciplines is working to demonstrate a process for rapid fabrication of CIS absorber layers which is suitable for the manufacture of high efficiency thin film modules. This process first deposits a thin 'seed' layer of large grain size CIS at low rate by a migration enhanced process, followed by high rate deposition of a mixed phase precursor material using a plasma assisted process. An analysis of the phase equilibria in the Cu-In-Se system has suggested the use of stacked binary compounds of CuSe, $Cu_3Se_2$ or $CuSe_2$ and InSe, $In_6Se_7$ or $In_4Se_3$ will produce a low temperature liquid phase to assist in the formation of large grain size CIS films. This work will verify the approach in CIS, extend it to CIGS, explore the use of Rapid Thermal Processing (RTP) and implement advanced process control strategies. The project will also investigate the use of the alternative buffer layer materials $In_x$ (OH,S) and Mg(S,Se).

**Status/Accomplishments:** Since initiation of the project in July 1998 the team has grown a variety of CIS compositions using the binary compound layered precursor structure. RTP of selected film structures has resulted in the formation of the $CuInSe_2$ phase. A detailed process model of an effusion cell has been developed to permit the comparison of different control strategies. Assessment of the Ga containing binary phase diagrams has begun and the Gibbs energy of formation of $Ga_2Se_3$ and GaSe have been measured by solid state galvanic cells. A new deposition system for depositing dielectrics has been purchased and installed. XFAS measurements using the Advanced Photon Source at Argonne has led to the suggestion of bond lengths in the $\alpha$ and $\beta$ CIS phases.

**Planned FY 1999 Milestones:** Milestones include the fabrication of CIS PV devices from stacked binary compound precursor films using RTP, establishing a CBD process for depositing MgSe and $In_x$(OH,S) films on, implement signal filtering and autocalibration for the flux sensors, assess the Ga-Se phase diagram, and complete software for predicting flux distribution and a Kalman observer.

**Major Articles Published in FY 1998:**


1. "Growth and Characterization of CdS Buffer Layers by CBD and MOCVD," C.-H. Chang, A.A. Morone, B.J. Stanbery, C. McCreary, M. Huang, C.-H. Huang, S.S. Li and T.J. Anderson, submitted to *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press) .
2. "Engineered Phase Inhomogeneity for CIS Device Optimization," B.J. Stanbery, C.-H. Chang and T.J. Anderson, accepted to 11th Int. Conf. Ternary and Multinary Compounds (1997).
3. "Investigation of Buffer Layer Processes on CIS Solar Cells by Dual Beam Optical Modulation Technique," S. Li, C.-H. Huang, B.J. Stanbery, C.H. Chang and T.J. Anderson, submitted to Proc. 26th IEEE Photovoltaic Specialists Conf., Anaheim, CA (1997).
4. "XPS Studies of Sodium Compound Formation and Surface Segregation in CIGS Thin Films," B.J. Stanbery, E.S. Lambers and T.J. Anderson, submitted to Proc. 26th IEEE Photovoltaic Specialists Conf., Anaheim, CA (1997).

# Processing of $CuInSe_2$-Based Solar Cells: Characterization of Deposition Processes in Terms of Chemical Reaction Analyses

| **Contract #:** XAF-5-14142-10 | **Contract Period:** 5/30/95–12/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Florida<br>Gainesville, FL 32611 | |
| | **Organization Type**: CU | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>T. Anderson<br>**Phone:** 352-392-0882 **Fax:** 352-392-9513 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1995: $250,000 — 1997: $225,146<br>1996: $124,167 — 1998: $200,590 | **Cost Share Funding:** |

**Project Objective:** The objective is to investigate the processing of CIS-based solar cells in order to enhance device performance and establish quantitatively processing-dependent variation in the solar cell absorber layers which may modify the CIS formation reactions. This research shall be carried out in close collaboration with and in support of NREL-managed research teams for CIS-based PV technology. This project supports the DOE PV Program goal of achieving a commercial, low-cost, 15% efficient thin-film photovoltaic module by the year 2005.

**Approach/Background:** Characterize optimized deposition schemes and chemical reaction pathways for $Cu(In,Ga)(Se,S)_2$-based solar cells.

**Status/Accomplishments:** Published thermodynamic reaction analysis for the formation of CIGS. Developed dual-beam optical modulation spectroscopy to measure lifetimes in thin-film semiconductor materials. Presented an Invited Paper at the 11th International Conference on Ternary and Multinary Compounds, Salford, U.K. (10/7-16/97).

**Planned FY 1999 Milestones:** Prepare Final Report.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** None.

## Thin-Film Technologies

# Properties of Wide-Gap Chalcopyrite Semiconductors for Photovoltaic Applications

| **Contract #:** XAK-8-176193-04 | **Contract Period:** 7/16/98–7/15/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Illinois<br>1-107 ESB, 1101 Springfield Ave.<br>Urbana, IL 61801 | |
| | **Organization Type**: CU | **Congressional District:** 15 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Angus Rockett<br>**Phone:** 217-333-0417 **Fax:** 217-244-2278 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>Electric Power Research Institute.<br>3412 Hillview Ave., P.O. Box 10412<br>Palo Alto, CA 94303 |
| | **DOE Funding Allocation:**<br>1998: $16,000 | **Cost Share Funding:**<br>1998: $32,000 |

**Project Objective:** The objectives of this project are to obtain fundamental understanding of wide-gap chalcopyrite semiconductors and photovoltaic devices. Information to be obtained includes significant new fundamental materials data necessary for accurate modeling of single and tandem-junction devices, new information on the basic materials science of wider-gap chalcopyrite semiconductors to be used in next-generation devices, and practical information on the operation of devices incorporating these materials.

**Approach/Background:** Thin-film epitaxial and polycrystalline layers of $Cu(In,Ga)(S,Se)_2$ will be produced and characterized. Deposition will use a hybrid sputtering and evaporation method shown previously to produce high-quality epitaxial layers of $Cu(InGa)Se_2$. Initial depositions of sulfide alloys will produce polycrystalline materials for purposes of rough stoichometry and deposition temperature determination. Upon satisfactory results on glass, we will switch to GaAs substrates and increase the deposition temperature consistent with our experience on deposition of selenides. We will characterize the layers using a wide array of state-of-the-art optical, electrical, microchemical and microstructural analysis available at the University of Illinois. These techniques will also be provided to assist members of the National CIS Team of which, through this contract, we are a member. We plan to determine the fundamental properties of $Cu(In,Ga)(S,Se)_2$ semiconductors as a function of composition and deposition conditions. Further, we plan to produce solar cells from these materials and determine the factors limiting performance of the devices based on analysis of the materials and device results.

**Status/Accomplishments:** Completed design and construction in progress for a S effusion cell to retrofit to the existing deposition system to allow S alloy deposition. Modeling of device performances based on data and novel concepts developed previously is in progress. Analysis of material as part of the CIS Team underway in collaboration with several other team members including one university group and four industrial groups.

**Planned FY 1999 Milestones:** Publication of three papers in collaboration with CIS Team members. Deposition of single crystal and polycrystalline $Cu(In,Ga)(S,Se)_2$. Preliminary fabrication of devices based on these materials. Hall-effect characterization of thin films and epitaxial layers.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:**

A. Rockett, "The Electronic Effects of Point Defects in $Cu(In_x,Ga_{1-x})Se_2$ Devices," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

A. Rockett, K. Granath, S. Asher, M.M. Al-Jassim, F. Hasoon, R. Matson, B. Basol, V. Kapur, J.S. Britt, T. Gillespie, and C. Marshall, "Na Incorporation in Mo and $CuInSe_2$ from Production Processes," in preparation, planned for submission by late 1998.

## Thin-Film Technologies

# Search for Factors Determining the Photodegradation in High-Efficiency a-Si:H-based Solar Cells

| **Contract #:** XAK-8-17619-11 | **Contract Period:** 1/16/98–1/15/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of North Carolina at Chapel Hill<br>Dept of Physics & Astronomy<br>Chapel Hill, NC 27599-3255 | |
| | **Organization Type**: CU | **Congressional District:** 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Daxing Han<br>**Phone:** (919)-962-5002 **Fax:** (919)-962-0480 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $101,250 | **Cost Share Funding:** |

**Project Objective:** The objective of this work is to develop improved understanding of carrier collection and open-circuit voltage limitations of a-Si:H-based solar cells. These limitations will be described in terms of transport properties and recombination losses via midgap and tail-state defects. The work will verify or disprove the role of hydrogen diffusion as the cause of the metastability.

**Approach/Background:** Study a-Si:H-based materials and devices using the following spectroscopies: (1) Electroluminescence (EL) Spectroscopy; (2) Internal Electric Field Profile, Ei(x), using a null-current technique to measure the interface electric field profile in p-i-n solar cells; (3) Photothermal Bending Spectroscopy (PBS) as an innovative techniques to characterize the complex photodegradation mechanisms; (4) Nuclear Magnetic Resonance (NMR) and MQ NMR to study the hydrogen microstructure and its dynamics.

**Status/Accomplishments:** Based on systematic studies, we have developed a complete model to explain the features of the EL as dispersive-transport-controlled non-geminate recombination processes. Preliminary results show that the more stable $V_{OC}$ is related to a strong electric field strength near the p-i interface in H-diluted cells. Studies of (a) a-SiGe:H solar cell performance in relation to the internal electric field profile and density localized states in the i-layer; (b) the transport properties in relation to microstructures of films from a-Si to μc-Si have been completed. Preliminary results show that a small change of the stress such as light-induced metastable changes in a-Si:H films can be detected by acoustic resonance measurements. The high-temperature NMR spectra from 20 C to 250 C in both glow discharge and hot-wire materials were studied.

**Planned FY 1999 Milestones:** (1) Complete a detailed characterization of H-motion, -bonding, and light-induced changes in hot-wire material in comparison to glow discharge material; (2) Establish the feasibility to detect hydrogen motion in a-Si:H by measuring NMR spectra above room temperature; (3) Establish the null-current forward bias transient method to separate degradation of the bulk absorber region and of the junction regions.

**Major Reports Published in FY 1998:** none, new subcontract

**Major Articles Published in FY 1998:**

1. Daxing Han, et.al., MRS Symp. Proc. Vol **505** (Material Research Society, 1998), 3 articles
2. Daxing Han, T. Gotoh, M. Nishio, T. Sakamoto, S. Nonomura, S. Nitta, Q. Wang, E. Iwaniczko, and A.H. Mahan, to be published in NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998; AIP Conference Proceedings (in press)

# Identifying Electronic Properties Relevant to Improving Stability in a-Si:H Based Cells and Overall Performance in a:SiGe:H Based Cells

| **Contract #:** XAN-4-13318-07 | **Contract Period:** 4/18/94–01/15/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Oregon<br>Eugene, OR 97403 | |
| | **Organization Type**: CU | **Congressional District:** 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J.D. Cohen<br>**Phone:** 541-346-4775 **Fax:** 541-346-3422 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $70,500 — 1997: $96,000<br>1995: $123,000 — 1998: $33,000<br>1996: $133,000 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States ensuring that this industry remains a world leader in the a-Si technology; help the U.S. amorphous silicon PV industry to achieve the U.S./DOE PV Program FY 1995 milestone of 10% stable efficiency commercial thin-film modules; help the U.S. amorphous silicon PV industry to achieve 12% stable efficiency commercial thin-film modules by 1998; achieve 15% stable efficiency multi-junction a-Si:H modules for large-scale utility use by the year 2005.

**Approach/Background:** Analyze amorphous silicon materials and devices using capacitance spectroscopy techniques.

**Status/Accomplishments:** Fully characterized the latest a-SiGe:H and "hydrogen diluted" a-Si:H layers. Established the importance of defect relaxations. Principal Investigator is team leader of Metastability and Mid-Bandgap Amorphous Silicon Team.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Subcontract Report, NREL/SR-520-25802 (November 1998).

**Major Articles Published in FY 1998:** None.

# Identifying Electronic Properties Relevant to Improving Stability in a-Si:H Based Cells and Overall Performance in a-SiGe:H Based Cells

| **Contract #:** XAF-8-17619-05 | **Contract Period:** 1/16/98–1/15/02 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Oregon<br>Eugene, OR 97403 | |
| | **Organization Type**: CU | **Congressional District:** 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J.D. Cohen<br>**Phone:** 541-346-4775 **Fax:** 541-346-3422 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $97,600 | **Cost Share Funding:** |

**Project Objective:** The objectives of this subcontract are to: develop a cost-effective amorphous silicon PV technology to foster a viable amorphous silicon PV industry in the United States. This will carried out within the context of two of the research and developments sub-Teams established by the NREL/EPRI Thin Film Partnership. Our effort will focus on the characterization of the electronic properties of a-Si:H and a-SiGe:H films obtained from a variety of outside sources, most of which will be compared with the performance of companion p-i-n cells. Ultimately the goal of the Amorphous Silicon Team is to achieve 15% stable thin-film modules by 2005.

**Approach/Background:** To characterize the properties of these a-Si:H and a-SiGe:H alloys using junction capacitance spectroscopic techniques, including drive-level capacitance profiling, transient photocapacitance and transient junction photocurrent spectroscopies, modulated photocurrent methods. On some occasion, ESR spectroscopy will also be employed.

**Status/Accomplishments:** In the first 6 months of this Subcontract films of high-hydrogen dilution produced at USSC were characterized to look for effects of medium range order. The degradation kinetics of mixed phase a-Si:H/microcrystalline Si samples were characterized. We also examined our defect data for intrinsic and lightly doped a-SiGe:H samples produced at USSC to assess whether it was consistent with charged defect formation models.

**Planned FY 1999 Milestones:** Examine ECR a-SiGe:H electronic properties produced at Iowa State. Examine electronic properties of a-Si:H films as a function of deposition rate. Continue to assess properties of a-Si:H material grown with high hydrogen dilution. Examine electronic properties of a-SiGe:H alloys in the mid-gap regime (Ge concentrations below 20at.%). Correlate electronic properties with matched p-i-n cells wherever possible.

**Major Reports Published in FY 1998:** *none due*

**Major Articles Published in FY 1998:**

C.-C. Chen, F. Zhong, J.D. Cohen, J.C. Yang, and S. Guha, "Evidence for charged defects in intrinsic glow discharge hydrogenated amorphous silicon-germanium alloys", Physical Review B(Rapid)**57**, R4210 (1998); J. David Cohen, "Electronic structure of a-Si,Ge:H", Book chapter prepared for *Properties of Amorphous Silicon and Its Alloys*, ed. by Tim Searle (EMIS Datareview series, London, 1998), pp. 180-187; Y. Lubianiker, R.R. Lowe-Webb, J.D. Cohen, H.-C. Jin and J.R. Abelson, "Degradation kinetics of a-Si:H: The effect of embedded microcrystallites", Mat. Res. Soc. Symp. Proc.. 1998, in press.

# Advanced Processing of CdTe- and $Cu(In,Ga)Se_2$-Based Solar Cells and Submodules

| **Contract #:** XAF-5-14142-09 | **Contract Period:** 4/18/95–5/31/98 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of South Florida<br>Tampa, FL 33620 | |
| | **Organization Type**: CU | **Congressional District:** 11 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D.L. Morel — **Phone:** 813-974-2508 **Fax:** 813-974-5250<br>C. Ferekides — **Phone:** 813-974-4818 **Fax:** 813-974-5250 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1995: $286,582 1997: $264,332<br>1996: $167,413 1998: $188,524 | **Cost Share Funding:** |

**Project Objective:** The objective is to investigate the processing of CdTe and Copper Indium/Gallium Diselenide based solar cells in order to enhance device performance and establish processing reliability. This research shall be carried out in close collaboration with and in support of NREL-managed research teams for Copper Indium/Gallium Diselenide and CdTe based technologies. to meet the DOE goal set for the year 2005 to achieve commercial, low-cost, 15% efficient thin film photovoltaic modules.

**Approach/Background:** Develop robust processing schemes for CdTe and CIGS solar cells and identify how differences in processing affect solar cell performance. Start text here

**Status/Accomplishments:** PI is subteam leader of CdTe team. Detailed characterization of junction formation in CdS/CdTe solar cell junctions. Fabricated CIGS solar cells with voltages >400mV. Identified Ga-alloying to be critical in determining VOC, regardless of bandgap increase due to alloying.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Report, to be published.

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press

## Thin-Film Technologies

# Advanced Processing Technology for CdTe and High Band Gap CIGS Solar Cells

| **Contract #:** ZAF-8-17619-29 | **Contract Period:** 5/26/98–7/25/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of South Florida<br>4202 E. Fowler Ave.<br>Tampa, FL 33620 | |
| | **Organization Type**: CU | **Congressional District:** 11 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. L. Morel and C. S. Ferekides<br>**Phone:** 813-974-2508 and 813-974-4818 **Fax:** 813-974-5250 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>EPRI (Special Topic) |
| | **DOE Funding Allocation:**<br>1998: $172,461 | **Cost Share Funding:**<br>1998: $66,316 |

**Project Objective:** The objectives of this work are to develop improved solar cell processing schemes for CdTe and CIGS based solar cells which are capable of further enhancing the performance and long-term stability and to reduce the manufacturing costs of commercial thin-film photovoltaic modules. Important aspects of the research will be to develop improved understanding and insights to how process modifications affect device performance. CIGS cells with wide band gaps of the absorber layer will be produced and evaluated as suitable candidates for CIS-based tandem devices.

**Approach/Background:** For both CdTe and CIGS based technologies we will fabricate and evaluate complete device structures. Although some devices will be fabricated on substrates such as 7059 glass for evaluative purposes, most devices will use soda lime glass, the industry standard. The process approaches, which we will develop, will be consistent with the realities of manufacturability. Stability testing of select devices will also be conducted under appropriate simulation conditions to relate any observed instabilities to process parameters.

**Status/Accomplishments:** In the CIGS area we are focusing on understanding the processing conditions that lead to optimum Ga incorporation. We have observed an interference with effective incorporation caused by background Se. To improve control of this mechanism we are modifying our processing equipment. In the CdTe area we continue the development of all-CSS devices. Emphasis has now shifted on transferring the process onto inexpensive soda lime glass substrates. We have also begun stability studies, which are currently focusing on temperature stressing of the devices. To support of our stability work, we have to date developed, in addition to the baseline doped graphite contact, $Cu_xTe$ and ZnTe based contacts. In all cases we have demonstrated state of the art performance with $V_{OC}$'s over 830 mV and ff's over 70%. We also continue our investigation of alternative TCO's.

**Planned FY 1999 Milestones:** a) A determination of the key processing parameters required to obtain simultaneously good surface and bulk properties of CIGS and CGS absorbers. b) Development of an understanding of whether the optimum processing of the absorber and window layers is similar or dissimilar for CIGS and CGS cells. c) A determination of the key processing requirements for CSS deposited CdS for high efficiency CdTe cells. d) Development of back contacts for CdTe solar cells. e) A determination of which new TCO materials are viable window layers for high efficiency CdTe cells.

**Major Reports Published in FY 1998:** none yet, new subcontract

**Major Articles Published in FY 1998:**


1. A. Jayapalan, H. Sankaranarayanan, H. Lin, R. Narayanaswamy, C. S. Ferekides and D. L. Morel, "Determination of Fundamental Parameters and Mechanisms in CIGS Solar Cells Using Photocapacitance Techniques", Proceedings of the Second World PV Conference, Vienna, July, 1998.
2. R. Narayanaswamy, H. Sankaranarayanan, R. Bhatt, H. Lin, M. Shankaradas, C. S. Ferekides and D. L. Morel, "Achievement of High Jsc's in ZnO/CIGS Heterojunctions Using Reactively Sputtered ZnO", Proceedings of the Second World PV Conference, Vienna, July, 1998.
3. C. S. Ferekides, S. Marinskaya, D. Marinskiy, V. Palekis and D. L. Morel, "CdTe/ZnSe Junctions and Solar Cells", Proceedings of the Second World PV Conference, Vienna, July, 1998.

## Thin-Film Technologies

# High Efficiency Thin-Film Cadmium Telluride and Amorphous Silicon-Based Solar Cells

| **Contract#:** ZAF-8-17619-14 | **Contract Period:** 3/4/98–3/3/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | The University of Toledo<br>2801 W. Bancroft<br>Toledo, OH, 43606 | |
| | **Organization Type:** IN | **Congressional District:** 9 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>A.D. Compaan (P.I.) and X. Deng (co-P.I.)<br>**Phone:** 419-530-4787 / -4782 **Fax:** 419-530-2723 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** 303-384-6480<br>**Fax:** 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>The University of Toledo |
| | **DOE Funding Allocation:**<br>1998: $253,500 | **Cost Share Funding:**<br>1998: $174,435 |

**Project Objectives:** To develop improved solar cell processing schemes for CdTe-based and for a-Si:H-based solar cells which can further enhance the performance and long-term stability of these devices and/or reduce the manufacturing costs of commercial thin-film photovoltaic modules based on these devices.

**Approach/Background:** The CdTe-based cell effort is focused on the use of planar magnetron sputtering for deposition of the active semiconductor layers as well as the electrode/contact structures. The a-Si:H-based effort is focused on plasma-enhanced chemical vapor deposition (PECVD) of a-Si:H, a-Si:Ge:H as well as polycrystalline and nanocrystalline forms of these materials. Devices are tested by current-voltage, quantum efficiency, and photovoltage measurements. The cell fabrication efforts are supported by characterization studies which include photoluminescence, Raman scattering, optical absorption, SEM, EDS, x-ray diffraction, Hall effect, conductivity, and capacitance-voltage measurements.

**Status/Accomplishments:** The UT group has fabricated triple-junction a-Si/a-SiGe/a-SiGe devices with ~10% efficiency and reached 11.6% efficiency in an all-sputtered CdS/Cdte cell. To improve fundamental understanding of the interface, CdS/CdTe bilayers have been studied by synchrotron x-ray scattering, and the alloy system CdSTe has been investigated with measurements of lattice constant, phonon frequencies, band gaps, and the real and imaginary parts of the optical dielectric constants.

**Planned FY 1999 Milestones:** In addition to active participation in teaming activity, work will include study of high sputter deposition rates, thin CdTe, doping by reactive sputtering, stress effects on cells; optimization of triple-junction a-Si devices; improved ordering of SiGe alloys by, *e.g.,* hydrogen dilution; further optimization of sputtered ITO and ZnO.

**Major Reports Published in FY 1998:** none (new subcontract)

**Major Articles Published in FY 1998:** (selected list)


- X. Deng, "Study of Triple Junction Amorphous Silicon Alloy Solar Cells;" D. Grecu & A.D. Compaan, "Photoluminescence Study of Cu Diffusion in CdTe;" "A.D. Compaan, I. Matulionis, and S. Nakade, "Lasers and Beam-Delivery Options for Polycrystalline Thin-Film Scribing" *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).
- Fischer, L. Anthony and A.D. Compaan, "Raman Analysis of Short-Range Clustering in Laser-Deposited $CdS_xTe_{1-x}$ Films," Appl. Phys. Lett. **72**, 2559, (1998).
- R. Wendt, A. Fischer, D. R. Grecu and A.D. Compaan, "Improvement of CdTe solar cell performance with discharge control during film deposition by magnetron sputtering," J. Appl. Phys. **84**, 2920-2925 (1998).
- Y.L. Soo, S. Huang, Y.H. Kao, and A.D. Compaan, "Investigation of interface morphology and composition mixing in CdTe/CdS heterojunction photovoltaic materials using synchrotron radiation," J. Appl. Phys. **83**, 4173 (1998).
- R. Wendt, A.D. Compaan, D. Grecu, K. Makhratchev, X. Ma, and R.G. Bohn, "CdTe Cell Performance vs. Plasma Parameters during Magnetron Sputter Deposition," (paper VD5.13); X. Deng, G. Miller, R. Wang, L. Xu, and A.D. Compaan, "Study of Sputter Deposition of ITO Films for a-Si:H n-i-p Solar Cells," (paper VB5.22), 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion--proceedings (Vienna, Austria, 6-10 July 1998).

## Thin-Film Technologies

# High-Efficiency Thin-Film Cadmium-Telluride-Based Solar Cells

| **Contract #:** ZAX-4-14013-01 | **Contract Period:** 1/21/94–3/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Toledo<br>2801 West Bancroft Street<br>Toldeo, OH 43606 | |
| | **Organization Type**: CU | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>A. Compaan<br>**Phone:** 419-530-4787 **Fax:** 419-530-2723 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>University of Toledo. |
| | **DOE Funding Allocation:**<br>1994: $117,848 — 1997: $137,100<br>1995: $125,000 — 1998: $000,000<br>1996: $108,900 | **Cost Share Funding:**<br>1994: $113,227 — 1997: $117,126<br>1995: $120,098 — 1998: $000,000<br>1996: $126,825 |

**Project Objective:** The objectives for the research are to further advance the prospects of LPVD and rf-SP deposited CdTe-based solar cells; to investigate alloying of CdS and CdTe (e.g., with Hg and Zn) to achieve bandgap variations and perhaps improved contacts; and to provide support wherever possible for the efforts of Solar Cells Inc. and other NREL subcontractors. This project will help meet the DOE goal set for the year 2005 to achieve commercial, low-cost, 15% efficient thin-film photovoltaic modules.

**Approach/Background:** Optimize the performance of CdTe-based solar cells prepared by radio frequency sputtering.

**Status/Accomplishments:** Contributed to the CdS thickness study of the CdTe team, achieving an efficiency of 11.6% (highest efficiency for sputter-deposited CdTe cell). Completed Final Report.

**Planned FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998

**Major Articles Published in FY 1998:**
Final Report, NREL/SR-520-25856, 11/98.

## Thin-Film Technologies

# Optimization of Laser Scribing for Thin-Film PV Modules

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| **Contract #:** ZAF-5-14142-08 | **Contract Period:** 4/12/95–10/11/97 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Toledo<br>Toledo, OH 43606 | |
| | **Organization Type**: CU | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>A.D. Compaan<br>**Phone:** 419-530-2147 **Fax:** 419-530-2723 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>University of Toledo |
| | **DOE Funding Allocation:**<br>1995: $125,000<br>1996: $130,000 | **Cost Share Funding:**<br>1995: $21,044<br>1996: $23,141 |

**Project Objective:** The objective is to investigate new laser scribing processes that improve the reliability, performance, and cost-effectiveness for the monolithic interconnection of large area polycrystalline thin-film photovoltaic modules. This research shall be carried out in close collaboration with and in support of research teams for CIS- and CdTe-based PV technologies. This project will contribute to meeting the DOE goal set for 2005 of achieving commercial, low-cost, 15% efficient thin-film photovoltaic modules.

**Approach/Background:** Characterize the ablation characteristics and resulting scribes of different laser systems for layers used in CuInSe2- and CdTe-based PV devices.

**Status/Accomplishments:** Quantitatively characterized the scribing characteristics of various laser systems for various materials used in thin-film solar cells.

**Planned FY 1999 Milestones:** None

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Final Report, NREL/SR-520-24842.

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

## Thin-Film Technologies

# Characterization of Amorphous Silicon Thin Films and PV Devices

| **Contract#:**XAK-8-17619-13 | **Contract Period:** 1/14/98–1/13/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | University of Utah<br>Salt Lake City, UT<br>84112 | |
| | **Organization Type:** CU | **Congressional District:** 2 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>P. Craig Taylor<br>**Phone:** 801-581-8751 **Fax:** 801-581-4246 (or 801-581-4801) | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** 303-384-6480<br>**Fax:** 303-384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1998: $63,400 | **Cost Share Funding:** |

**Project Objective:** The objective of the research is to characterize the defects, impurities and metastabilities in hydrogenated amorphous silicon (a-Si:H), in hydrogenated amorphous silicon-germanium alloys (a-$Si_xGe_{1-x}$:H) and in other related alloys of importance to photovoltaic devices. Of special interest is to develop an understanding of the degradation of a-Si:H and related alloys and to pursue options to eliminate this degradation.

**Approach/Background:** Various optical and magnetic resonance techniques are employed to examine the role of defects , impurities and metastabilities in a-Si:H and related alloys. Optical techniques include photothermal deflection spectroscopy to measure low levels of optical absorption, photoluminescence and photoluminescence excitation spectroscopy, and various modulated optical spectroscopies. Magnetic resonance techniques include electron spin resonance and optically detected magnetic resonance. Measurements are made on individual films and on device structures.

**Status/Accomplishments:** We have demonstrated the feasibility of using second harmonic detection of electron spin resonance (ESR) to enhance signal-to-noise ratios and used this technique to measure samples supplied by other participants in the PV thin film partnership. Preliminary results show that hydrogen dilution does not significantly affect the optically induced production of neutral silicon dangling bonds even though there appears to be an improvement in the stability of cells made using the hydrogen-dilution process. Further experiments on both cells and individual layers are necessary to confirm this conclusion. We have shown that the saturated ESR spin density for a hydrogenated silicon sulfur alloy is somewhat less than for a-Si:H. Molecular hydrogen has been measured in several hot-wire samples of a-Si:H supplied by NREL. Preliminary measurements indicate that the molecular hydrogen in the hot wire material is typically less than that in the PECVD material. We have accepted delivery of a three-chamber, load-locked PECVD system from MVSystems and begun making films.

**Planned FY 1999 Milestones:** We plan to examine the kinetics of the production and annealing of silicon dangling bond defects at low temperatures using our second-harmonic detection scheme for electron spin resonance (ESR), which greatly enhances the signal-to-noise ratios. Our preliminary results indicate that, at low temperatures, electrons and holes trapped in localized band-tail states compete with the production of silicon dangling bonds and make the interpretation of previous photoconductivity measurements difficult. We will measure the temperature dependence of the kinetics, including the dispersion, for the production of silicon dangling bonds in a-Si:H and related alloys. Comparisons between PECVD and hot wire samples will be made. We plan to produce p-i-n cells in our new 3-chamber, PECVD system.

**Major Reports Published in FY 1998:** none, new subcontract

**Major Articles Published in FY 1998:**

"Defect Structure in Nitrogen-Rich Amorphous Silicon Nitride Films" (with B. Yan and J. H. Dias da Silva), *J. Non-Cryst. Solids* **227**, 528 (1998).

"Relaxation to Hopping Conductivity in Sulfur-Doped Hydrogenated Amorphous Silicon" (with J.-H. Yoon), *J. Non-Cryst. Solids* **227**, 385 (1998).

"Light-Induced Recombination Centers in Hydrogenated Amorphous Silicon-Sulfur Alloys" (with J.-H. Yoon and Czang-Ho Lee), *J. Non-Cryst. Solids* **227**, 324 (1998).

*Amorphous Silicon and its Alloys* (INSPEC, London, 1998), Tim Searle, ed., "ESR and LESR of Gap States in a-Si:H", p. 139.

## Thin-Film Technologies

# Alternative Window Schemes for $CuInSe_2$-Based Solar Cells

| **Contract #:** XAF-6-15375-01 | **Contract Period:** 11/3/95–12/31/97 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Washington State University<br>Pullman, WA 99164-3140 | |
| | **Organization Type:** CU | **Congressional District:** 5 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>L.C. Olsen<br>**Phone:** (509) 372-7221 **Fax:** (509) 372-7100 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** (303) 384-6480<br>**Fax:** (303) 384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1996: $ 83,750 1997: $ 87,500 | **Cost Share Funding:** |

**Project Objective:** The objective is to develop window alternatives (replacing CdS) for $Cu(In,Ga)Se_2$ solar cells to meet the DOE goal set for the 2005 to achieve commercial, low-cost, 15% efficient thin-film photovoltaic modules.

**Approach/Background:** The approach is to optimize MOCVD-deposited alternative window layers and obtain state of the art Cu(In,Ga)Se2 solar cells. Emphasis is placed on investigations of ZnO and ZnSe compounds as replacements for CdS.

**Status/Accomplishments:** Approaches to growth of thin crystalline layers of ZnO and ZnSe by MOCVD onto $Cu(In,Ga)Se_2$ absorbers have been developed and applied to solar cells. A viable processing sequence to deposit ZnO window layers was developed and utililized to fabricate a cell based on NREL $Cu(In,Ga)Se_2$ material with an active area efficiency of 14 %.

**Planned FY 1999 Milestones:** Project completed.

**Major Reports Published in FY 1997:** Final Report NREL/SR-520-25613 (10/98)

**Major Articles Published in FY 1997:**
*"High Efficiency CIGS and CIS Cells With CVD ZnO Buffer Layers,"* Presented at 26th IEEE PV Specialists Conf., Anaheim, CA, 9/29–10/3/97.

## Thin-Film Technologies

# Alternative Window Schemes for $CuInSe_2$-Based Solar Cells

| **Contract #:** XAF-8-17619-06 | **Contract Period:** 12/29/97–12/18/00 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Washington State University<br>Pullman, WA 99164-3140 | |
| | **Organization Type:** CU | **Congressional District:** 5 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>L.C. Olsen<br>**Phone:** (509) 372-7221 **Fax:** (509) 372-7100 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone:** (303) 384-6480<br>**Fax:** (303) 384-6531 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1998: $ 138,700 | **Cost Share Funding:**<br>None |

**Project Objective:** The objective is to develop window alternatives (replacing CdS) for $Cu(In,Ga)Se_2$ solar cells to meet the DOE goal set for the 2005 to achieve commercial, low-cost, 15% efficient thin-film photovoltaic modules.

**Approach/Background:** The approach is to optimize MOCVD-deposited alternative window layers and obtain state of the art Cu(In,Ga)Se2 solar cells. Emphasis is placed on investigations of ZnO, ZnSe and ZnS compounds as replacements for CdS, and on optimization of the complete process of cell fabrication. In particular, approaches to growth of window layers compatible with subsequent processing steps including TCO and collector grid deposition that yield stable, efficient solar cells are being investigated.

**Status/Accomplishments:** Approaches to growth of thin crystalline layers of ZnO and ZnSe by MOCVD onto $Cu(In,Ga)Se_2$ were developed in previous programs. Capabilities for MOCVD deposition of ZnS and sputtering conductive ZnO for TCO films are being added.

**Planned FY 1998 Milestones:** Demonstrate proof of concept results for ZnS window layers. Fabricate an efficient complete solar cell based on CIGS, an alternative window layer, a TCO, collector grids and $MgF_2$ AR coating with all processes beginning with the window layer being done by the subcontractor.

**Major Reports Published in FY 1998:** none (new subcontract)

**Major Articles Published in FY 1998:**
*NREL/SNL Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, September, 1998;* to be published AIP Conference Proceedings.

## Thin-Film Technologies

# Identifying and Overcoming Degradation Mechanisms in CdTe Solar Cells

| **Contract #:** AAK-7-17619-15 | **Contract Period:** 8/1/98–7/1/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Weizman Institute of Science<br>Rehovot, Israel | |
| | **Organization Type**: CU | **Congressional District:** |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>David Cahen, G. Hodes, K. Gartsman<br>**Phone:** + 972-8934-2246 **Fax:** + 972-8934-4139 | |
| **Technical Monitor:**<br>B. von Roedern<br>**Phone**: 303-384-6480<br>**Fax**: 303-384-6531 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $34,000 | **Cost Share Funding:** |

**Project Objective:** Develop improved understanding of the mechanisms leading to degradation of CdTe solar cells during their use and the testing of various ways to reduce such degradation.

**Approach/Background:** We will check the assumption that atomic migration of contact constituents is involved in the device degradation. For this we need to identify and measure such atom mobility. For this purpose several techniques that have been used by us in single crystals will need to be adapted for use with polycrystalline thin films. These include the p/n junction motion and transient ion drift (capacitance decay). Subsequently new ways to make contacts as well as ways to prevent atom motion will be explored and their efficacy tested, by dome of the above-mentioned techniques. Prominent among these will be CdTe surface modifications.

**Status/Accomplishments:** During 1998, a start was made with the application of the p/n junction and transient ion drift methods to polycrystalline CdTe films on TCO as well as part of complete cell structures. Initial results have been obtained, suggesting the feasibility of the transient ion drift method on the films. The films as well as the cell structures can now also be characterized electrically and optically in-house, something that is critical because of the need to identify basic parameters, that can be influenced by the various surface treatments and contact material applications.

**Planned FY 1999 Milestones:** Establish experimental capabilities to measure diffusion of species in CdTe solar cells. Complete experiments aimed at separating degradation effects in back contact region from those in the absorber and front junction regions, for devices with commonly used back contacts.

**Major Reports Published in FY 1998:** None directly relevant to this contract.

**Major Articles Published in FY 1998:** None directly relevant to this contract.

# TECHNOLOGY DEVELOPMENT

# Next Generation Three-Phase Inverters

| **Contract #:** ZAF-5-14271-10 | **Contract Period:** 9/28/95–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Advanced Energy Systems<br>Box 262, Riverview Mill<br>Wilton, NH 03086 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. Wills<br>**Phone:** 603-654-9322 **Fax:** 603-654-9324 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Advanced Energy Systems, LTD |
| | **DOE Funding Allocation:**<br>1995: $528,101<br>1996: $66,000)<br>1997: $210,235<br>1998: $135,687<br>(WE $53,212) | **Cost Share Funding:**<br>1995: $165,855<br>1996: $20,728<br>1997: $66,026<br>1998: $41,954<br>($16,711) |

**Project Objective:** To develop "Next Generation" Three-Phase inverters for the remote/village power & grid-connect markets. The target power was 60 kW for the village/stand-alone product, and 50 kW for the grid connect product.

**Approach/Background:** The 60 kW village power inverter and hybrid system controller is based on designs originally developed by AES LTD (Perth, Australia). A new 20 kW power module was developed based on: a single bonded--fin heat sink; state of the art IGBT power switches; new design IGBT driver boards that are highly noise immune and provide excellent switch protection; and new passive components such as Amorphous Core materials (Metglas) and metalized polypropylene capacitors. Three power modules are used in the 60 kW three-phase inverter. They are controlled by a new three-phase control card that performs many functions digitally and is more capable, less expensive and smaller (replacing four individual boards of the original design) than the originals

The 50 kW line tie inverter is an innovative design in that it: is accurately current controlled; has current THD less that one percent; can be either a transformer-based topology (for standard commercial applications requiring a grounded PV array) or transformerless (for applications behind the utility fence requiring minimal cost).

**Status/Accomplishments:** The 60 kW hybrid inverter was tested at Sandia National Labs (SNL), where evidence of "transformer walkup" was observed. Later work at NREL's hybrid test bed solved this problem, and the inverter operated successfully in all modes, and with up to 100 kW of load for as long as 10 seconds. This design is now being manufactured and is being fielded worldwide. The 50 kW grid-tie inverter was tested at SNL.

**Planned FY 1999 Milestones:** N/A

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Cost Reduction and Manufacture of the SunSine™325 AC Module

| **Contract #:** ZAX-8-17647-03 | **Contract Period:** 4/21/98–6/20/00 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Ascension Technology, Inc.<br>P.O. Box 6314<br>Lincoln, MA 01773-6314 | |
| | **Organization Type**: IN | **Congressional District:** 7 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>E. C. Kern, Jr.<br>**Phone:** 781-684-6101 **Fax:** 781-890-2050 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Ascension Technology, Inc. |
| | **DOE Funding Allocation:**<br>1998: $144,280 | **Cost Share Funding:**<br>1998: $61,834 |

**Project Objective:** The objective of this subcontract over its two-year duration is to continue to improve the manufacturability and reliability of the SunSine™ 325 AC Module and address design improvements in order to reduce the cost to manufacture the SunSine™325 inverter by 40-50% per unit over the present costs of the SunSine™300 inverter. This work will also boost the SunSine™ AC Module performance and enhance its marketability by adding customer-valued features. Planned specific advancements include: 40-50% reduction in inverter manufacturing costs; a 40% reduction in inverter footprint size from 169 to 100 square inches; a 4% increase in full power efficiency, from 87% to 91%; UL Listing; FCC certification, exports certifications; double production capacity from 2,500 to 5,000 units per year; achieve an initial installation failure rate less than 0.10 %; provide a standard 5-year warranty on the inverter portion of the product and achieve a rating of 250 Watts AC at PTC (PVUSA Test Conditions.

**Approach/Background:** Ascension Technology, Inc. will accomplish these advancements by improvements in the following areas. Manufacturing the aluminum enclosure and base plate will shift to a die-cast process, allowing significant cost reductions in quantity production. The electronic components will be repackaged to reduce the size of the unit. Soft switching or other modification in the power electronics will achieve cost reduction and increase in conversion efficiency. A review of and redesign of the control electronics will be performed to reduce the total number of components, parts costs, and improve design for manufacturability. Semi-automated test equipment will be designed to increase production throughput and quality. Integration of the PV laminate with the inverter will be investigated to streamline the final assembly and test procedures.

**Status/Accomplishments:** The soft-switching development is still in progress. Circuit board optimization is in progress, methods for repackaging the power electronics have been modeled, and some less expensive control electronic components have been identified. Evaluation of the conformal coating process has been completed and deemed suitable for use in this product. An in circuit test fixture has been developed and has increased the yield of circuit boards delivered from the stuffing operation. A semi-automated burn-in test station is being built. Some conceptual work on the new packaging of the product has been done

**Planned FY 1999 Milestones:**
Ascension will complte prototype SunSine™325s for anti-island, performance and HALT testing; complete testing of all electronic design improvements; omplete design, engineering and testing of semi-automated production test systems; and complete die-casting prototype.

**Major Reports Published in FY 1998:**
None.

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press) "Cost Reduction and Manufacture of the SunSine™325 AC Module".

## PVMaT

# Manufacture of an AC PV Module

| **Contract #:** ZAF-5-14271-05 | **Contract Period:** 7/25/95–6/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Ascension Technology, Inc.<br>P.O. Box 6314<br>Lincoln, MA 01773-6314 | |
| | **Organization Type**: IN | **Congressional District:** 7 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Dr. Edward C. Kern, Jr.<br>**Phone:** 781-684-6101 **Fax:** 781-890-2050 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Ascension Technology, Inc. |
| | **DOE Funding Allocation:**<br>1995: $189,418 1997: $75,942<br>1996: $189,418 1998: $31,277 | **Cost Share Funding:**<br>1995: $141,105 1997: $18,985<br>1996: $141,105 1998: $7,807 |

**Project Objective:** The objective of this project was to develop and establish initial production capacity for a SunSine™300 AC PV Module. Our goals in this project were to achieve UL Listing, to meet FCC Class B limits for unintentional radiators, to complete the AC module system design and development, advance the inverter design, design for manufacture, reliability, and serviceability, and to demonstrate commercialization through production and sale of 100 units. All of these project objectives were successfully met.

**Approach/Background:** The approach to commercializing the SunSine™300 AC PV Module included the following tasks. An Electric Utility design critique of the prospective design was conducted and used to target the product design. A third revision (Rev.3) of the inverter design was done, reducing harmonic current distortion, cost, size and efficiency. An aluminum casting was developed for packaging the inverter. Prototypes of the inverter were tested and ultimately Listed by UL. 12 PV laminates were manufactured at 300 Watts peak rating by sorting cells. Ten AC Module prototypes using the Rev.3 circuit board design were built for testing. Testing included environmental chamber testing for thermal cycling, humidity/freeze cycling, and damp heat. Testing also included outdoor performance at various sites including NREL, Sandia National Labs, and Ascension Technology, Inc. A special ac power quick-connector was developed for use with AC Modules to allow quick field connection of systems. An AC version of Ascension Technology's Listed PV Source Circuit Protector was developed. Ascension Technology's RoofJack™ mounting hardware for residential installations was improved. A Rev. 4 version of the SunSine™300 AC Module was developed based upon test results from the Rev. 3 design. This Rev. 4 version is the final version that went into Pilot Production. And finally, the resulting manufacturing and production processes were evaluated to determine strengths and weaknesses of the resulting process for use in later developments.

**Status/Accomplishments:** . The SunSine™300 AC PV Module has received the 1998 "Best of What's New" Award by Popular Science, to be published in the December 1998 issue. A pilot production run of 108 units was successfully completed in the spring of 1998. All of those units have been sold, shipped and installed at customer sites. The SunSine™300 is the first AC PV Module in the world to be Listed by Underwriters Laboratories. The SunSine™300 meets FCC Class B limits. An initial production capacity of 2,500 units per year has been established. This PVMaT 4A1 project is now complete with the one exception of completion of the final report.

**Planned FY 1999 Milestones:**
Deliver Final Report to NREL.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## PVMaT

# Cost Reductions in High Volume EFG PV Module Manufacturing Line

| **Contract #:** ZAX-8-17647-10 | **Contract Period:** 7/7/98–10/4/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | ASE Americas<br>4 Suburban Park Drive<br>Billerica, MA 01821-3980 | |
| | **Organization Type**: IN | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J. Kalejs<br>**Phone:** 978-667-5900 **Fax:** 978-663-7555 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>ASE Americas |
| | **DOE Funding Allocation:**<br>1998: $ 486,000 | **Cost Share Funding:**<br>1998: $ 526,500 |

**Project Objective:** Advance ASE Americas' PV manufacturing technologies in order to improve ASE manufacturing systems through improvements in process integration, Statistical Process Control implementation, data systems implementation, and ISO9000 and ISO14000 implementation.

**Approach/Background:** ASE Americas will meet these objectives through the development of low-cost manufacturing processes which can be scaled-up to high volumes in manufacturing; the growth of thin EFG tubes with improved productivity and production of solar cells from the resulting thin wafers; the improvement of laser cutting technology to obtain higher cutting speeds and stronger EFG wafers; and cell processing for improved efficiencies. Additionally, ASE shall investigate Flexible Manufacturing through the development of: large-area EFG wafers, continuous improvement, and advanced module manufacturing.

**Status/Accomplishments:** None – This subcontract has just been initiated.

**Planned FY 1999 Milestones:** Complete a turn-around-time (bottleneck) evaluation of EFG silicon material manufacturing line and identify key throughput barriers; a Nd:YAG laser beam delivery system design and construction; the design of hot zone for up to 50-cm diameter EFG cylinder; identify customer requirements for large area wafers and initial modifications to laser cutting system; complete performance testing of new Nd:YAG laser wafer cutting system, demonstrate increased cutting rate, and complete wafer edge characterization using new Nd:YAG wafer cutting; complete measurements of cutting performance with Nd:YAG and/or Copper Vapor lasers and wafer edge quality with the University of New Hampshire; complete characterization of wafers of 200-micron and 95-micron in thickness grown from EFG cylinders; complete modification of wafer handling system for large area wafers and mechanical yield evaluation of new laser cutting system.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Market Driven EFG Modules

| **Contract #:** ZAF-5-14271-13 | **Contract Period:** 12/14/95–5/1/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | ASE Americas<br>4 Suburban Park Drive<br>Billerica, MA 01821-3980 | |
| | **Organization Type**: IN | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>M. Kardauskas<br>**Phone:** 978-667-5900 **Fax:** 978-663-7555 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>ASE Americas |
| | **DOE Funding Allocation:**<br>1996: $ 435,000<br>1997: $ 453,000<br>1998: $ 368,000 | **Cost Share Funding:**<br>1996: $ 652,500<br>1997: $ 679,500<br>1998: $ 553,000 |

**Project Objective:** Advance ASE Americas' EFG wafer, cell and module manufacturing technology through manufacturing process research and development in order to reduce module production costs by 25% relative to pre-PVMaT 4A2 levels; increase average throughput and yield performance of the manufacturing line through application of Statistical Process Control (SPC) methods; and identify and evaluate modifications that will expand ASE Americas' commercial production capacity.

**Approach/Background:** ASE Americas met these objectives through manufacturing line improvements including a further decrease in the EFG wafer thickness, increase in the number of feet grown from a crucible in crystal growth, advances in the laser cutting technology for wafers, increase in as-grown EFG material electronic quality, improvements in solar cell fabrication technology, and improved fabrication processes and new designs for modules.

**Status/Accomplishments:** Implemented an overall module manufacturing cost reduction of 15% through individual advances in several areas: decreased wafer thickness to 275 microns, improved silicon feedstock utilization, and extended crystal growth lengths for a cost reduction of 6% in wafer production; improved purification procedures for graphite, and implemented the first phase of an SPC program to improve EFG solar cell efficiency and reduce module costs by 6.5% in cell fabrication; constructed and demonstrated equipment for removing phosphorus glass from diffused wafers that reduces acid consumption and fluoride waste by 95%; developed improved lamination process, designs and encapsulant for modules to reduce add-on costs in this area by 2.5%.

**Planned FY 1999 Milestones:** None – the research under this subcontract has been completed.

**Major Reports Published in FY 1998:**
NREL Photovoltaic Program FY 1997 Annual Report, *NREL/BK-210-23607,* (June 1998).
Kalejs, J., *"Market Driven EFG Modules," PVMaT Annual Subcontract Report,* NREL/SR-520-25817 (November 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)
J. Cao et al., Proceedings of the Twenty-Sixth IEEE Photovoltaic Specialists Conference, 1997.

# Large Area Silicon-Film™ Panels and Solar Cells

| **Contract #:** ZAF-5-14271-3 | **Contract Period:** 6/27/95–2/26/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | AstroPower, Inc.<br>Solar Park<br>Newark, DE 19716-2000 | |
| | **Organization Type**: IN | **Congressional District:** AL |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J. Rand<br>**Phone:** 302-366-0400 **Fax:** 302-368-6474 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>AstroPower, Inc. |
| | **DOE Funding Allocation:**<br>1995: $1,116,320<br>1996: $1,361,924<br>1997: $1,625,725<br>1998: $ 195,727 | **Cost Share Funding:**<br>1995: $ 787,006<br>1996: $ 960,156<br>1997: $1,145,726<br>1998: $ 136,014 |

**Project Objective:** Advance AstroPower's Silicon-Film™ cell and module manufacturing through manufacturing process research and development in order to reduce module production costs, increase average cell and module performance, and expand AstroPower's production capacity.

**Approach/Background:** AstroPower met these objectives by developing new cell and panel products and processes; improving cell performance; reducing the cost of critical baseline solar cell processes; developing processes for the manufacture of solar cells based on a 31-cm-wide Silicon-Film™ sheet; reducing manufacturing costs of the existing 16.5-cm-wide sheet process; and increasing production capacity of the 31-cm-wide Silicon-Film™ sheet to 20-MW/yr.

**Status/Accomplishments:** The AP225 Silicon-Film™ solar cell was taken to pilot-scale production. Efficiencies exceeding 12% were measured on this 240-$cm^2$ device. Laboratory scale devices demonstrated an efficiency of 16.6% (compared to a contract goal of 15.6%). All the processes and equipment were specified for full production in a new manufacturing facility. The site for the new facility was determined and fit up of the factory initiated. The new facility will result in reductions in manufacturing costs and increased throughputs.

**Planned FY 1999 Milestones:** None – This subcontract was been completed in FY1998.

**Major Reports Published in FY 1998:**
Rand, J.A., et.al., *"Large Area Silicon-Film™ Panels and Solar Cells," PVMaT Final Subcontract Report,* NREL/SR-520-25270 (September, 1998).
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Silicon-Film Solar Cells by a Flexible Manufacturing System

| **Contract #:** ZAX-8-17647-01 | **Contract Period:** 4/16/98–6/15/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | AstroPower, Inc.<br>Solar Park<br>Newark, DE 19716-2000 | |
| | **Organization Type**: IN | **Congressional District** AL: |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>J. Rand and J. Culik<br>**Phone:** 302-366-0400 **Fax:** 302-368-6474 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>AstroPower, Inc. |
| | **DOE Funding Allocation:**<br>1998: $874,734 | **Cost Share Funding:**<br>1998: $890,479 |

**Project Objective:** AstroPower is developing a manufacturing process for the production of large-area Silicon-Film™ solar cells in order to reduce solar-cell and module cost and expand production capacity. The objective is to develop a manufacturing system for a 50-MW fully integrated manufacturing plant that will produce a variety of panel and module products.

**Approach/Background:** The Silicon-Film™ process is presently in production at a new manufacturing facility in Newark, Delaware. The present process is based on the AP-225, a 240-$cm^2$ solar cell. Efficiencies exceeding 12% have been measured for the AP-225. Laboratory-scale devices have demonstrated an efficiency of 16.6%.

**Status/Accomplishments:** Recent work has focused on new processes and equipment capable of handling very large Silicon-Film™ planks in a low-cost, high-throughput, production environment. A flexible manufacturing system is being designed to produce a range of solar cell sizes from 3600-$cm^2$ planks. New solar cell processes developed for large planks include continuous large-area junction diffusion and AR coating. Processes under development include metallization and chemical etching.

**Planned FY 1999 Milestones:** Design and fabrication of a new Silicon-Film™ sheet manufacturing machine that will increase sheet speed by 100%; Demonstration of a 900-$cm^2$ solar cell with an efficiency of 10%; and Development of inline processes for the etching of Silicon-Film™ planks.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Production of Solar Grade (SoG) Silicon by Refining of Liquid Metallurgical Grade (MG) Silicon

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|---|---|
| **Contract #:** ZAX-8-17647-13 | **Contract Period:** 6/10/98–6/10/00 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Crystal Systems, Inc.<br>27 Congress St.<br>Salem, MA 01970 | |
| | **Organization Type**: IN | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Dr. Chandra P. Khattak<br>**Phone:** 978-745-0088 **Fax:** 978-744-5059 | |
| **Technical Monitor:**<br>M. Symko-Davies<br>**Phone**: 303-384-6528<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $143,500 | **Cost Share Funding:**<br>1998: $61,500 |

**Project Objective:** The objective of this PVMaT program is to produce solar grade (SoG) silicon feedstock by refining metallurgical grade (MG) silicon in the liquid state so that this material can be used as feedstock for ingot processes such as the Heat Exchanger Method (HEM) for photovoltaic applications. It is intended to continue this technology development in larger scale using thermo-chemical refining techniques and reduce the impurities in MG silicon to less than 1 ppma level.

**Approach/Background:** The approach is based on thermo-chemical refining of metallurgical grade (MG) silicon using the Heat Exchanger Method. The reduction of most impurities to less than one ppma level was demonstrated with approximately 3-kg charge of MG silicon with this approach. The present program will focus on the development of equipment and procedures for upgrading MG silicon to the SoG level consistent with theoretical analysis and experimental results. Prototype experiments will be carried out with about 500-kg charge size. The projected production cost of SoG silicon is less than $20/kg.

**Status/Accomplishments:** MG silicon from several suppliers has been obtained for refining tests. A laboratory scale reactor has been designed and set up for experimental work. Initial experiments have been carried out to develop refining procedures. A fused silica burner was designed for auxiliary heating of molten silicon to aid the refining step. During tests, it was concluded that this burner could be used for primary heating of MG silicon charge as well. It is also possible to use reactive carriers with the combustion gases of the burner for refining of MG silicon. Theoretical analysis has shown that all impurities in MG silicon, including boron (B) and phosphorus (P), can be reduced by slagging, reactions to form vapor species or operating under vacuum.

**Planned FY 1999 Milestones:** Select MG silicon sources for refining experiments based on analysis and experimental results. Complete theoretical analysis for developing procedures for refining of MG silicon and optimize these procedures based on experimental data. Conduct refining of MG silicon to SoG silicon experiments with charge sizes up to 50 kg and complete design and fabrication of a 150 kg refining system. Use the refined silicon as feedstock for HEM and demonstrate that all impurities in MG silicon, including B and P, can be reduced to less than 10 ppma levels.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
C. P. Khattak, F. Schmid, D. B. Joyce, E. A. Smelik and M. A. Wilkinson, " Production of Solar-Grade Silicon by Refining of Liquid Metallurgical-Grade Silicon", *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

# Efficiency and Throughput Advances in Continuous Roll-to-Roll a-Si Alloy Manufacturing Technology

| | |
|---|---|
| **Contract #:** ZAX-8-17647-09 | **Contract Period:** 6/22/98–8/21/01 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Energy Conversion Devices<br>1675 West Maple Road<br>Troy, MI 48084 | |
| | **Organization Type**: IN | **Congressional District:** 12 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>M. Izu<br>**Phone:** 810-280-1900 **Fax:** 810-280-1456 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Energy Conversion Devices |
| | **DOE Funding Allocation:**<br>1998: $ 572,000 | **Cost Share Funding:**<br>1998: $ 973,955 |

**Project Objective:** The objective of this subcontract over its three year duration is to continue the advancement of ECD's PV manufacturing technologies in order to support the PVMaT cost-reduction and capacity-increase goals with the development of manufacturing technologies which allow a 25-30% reduction in module cost ($/W) and a 60% increase in manufacturing capacity (MW/yr) over the United Solar 4$^{th}$ Quarter 1997 annualized manufacturing capacity.

**Approach/Background:** To accomplish these goals Energy Conversion Devices will: develop, fabricate and install a new substrate heating system and temperature sensor system designed to achieve more accurate temperature controlling and monitoring for the production of high-efficiency solar cells; develop, fabricate, and install a set of in-line real-time material quality monitoring systems for the United Solar Systems production machines; demonstrate the feasibility of using Zn metal targets in the DC sputtering process to prepare ZnO layers for high performance back-reflectors for incorporation of the process into United Solar's 5 MW amorphous silicon (a-Si) module production line; and redesign the internal hardware for the a-Si intrinsic layer deposition chambers used in the 5 MW United Solar production line.

**Status/Accomplishments:** None – This subcontract has just been initiated.

**Planned FY 1999 Milestones:** Demonstrate precise temperature control on pilot machine, using the prototype substrate heating system and rolling thermocouple and optical sensors; complete design, fabrication, installation of second generation sensor hardware for use in the a-Si pilot vacuum deposition machines; and complete installation of new sputtering process hardware into the pilot machine.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15$^{th}$ Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Advanced Polymer PV System

| **Contract #:** ZAF-5-14271-09 | **Contract Period:** 9/19/95–2/18/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Evergreen Solar, Inc.<br>211 2nd Ave.<br>Waltham MA 02451 | |
| | **Organization Type**: IN | **Congressional District:** 7 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Jack Hanoka<br>**Phone:** 781-890-7117 **Fax:** 781-890-7141 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Evergreen Solar, Inc. |
| | **DOE Funding Allocation:**<br>1995: $228,181 1997: $317,427<br>1996: $384,181 1998: $0 | **Cost Share Funding:**<br>1995: $57,045 1997: $79,358<br>1996: $96,435 1998: $0 |

**Project Objective:**
The objective of this subcontract was to reduce systems and component manufacturing costs through the use of innovative polymeric materials.

**Approach/Background:** By evaluating alternative materials for methods and materials used for encapsulation, backskin and module framing, significant reductions in system and component costs are expected.

**Status/Accomplishments:** A new backskin and a new encapsulant material for application without a vacuum, for PV modules was developed. The new materials allow fabricating of a frameless module with alternative mounting methods. Both the encapsulant and backskin allowed new module manufacturing methods. A hot-roll module lamination process was evaluated, and new module mounting methods identified. Five patents have been applied for.

**Planned FY 1999 Milestones:** N/A

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)
J.I. Hanoka, "Innovations in String Ribbon Module Manufacturing," 2nd World Photo World Conference and Exhibition on *Photovoltaic Energy Conversion; Proceedings of the 2nd Conference,* Vienna, Austria, August 1998

# Continuous, Automated Manufacturing of String Ribbon Si PV Modules

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|---|---|
| **Contract #:** ZAX-8-17647-07 | **Contract Period:** 5/21/98–5/21/01 |

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Evergreen Solar, Inc.<br>211 Second Avenue<br>Waltham, MA 02154 | |
| | **Organization Type**: IN | **Congressional District:** 7 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Dr. Jack Hanoka<br>**Phone:** 781-890-7117 x 19 **Fax:** 781-890-7141 | |
| **Technical Monitor:**<br>M. Symko-Davies<br>**Phone**: 303-384-6528<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Evergreen Solar, Inc.<br>. |
| | **DOE Funding Allocation:**<br>1998: $363,500 | **Cost Share Funding:**<br>1998: $55,786 |

**Project Objective:** A 7 MW crystalline silicon manufacturing line which is highly automated and virtually continuous.

**Approach/Background:** Exploit Evergreen's unique and innovative technology in the areas of silicon ribbon growth, cell making, and module manufacturing. Simplify processes such that cells and wafers are always horizontal, there is no insertion in and out of plastic carriers, and only one wet chemical step. Utilize developments in PVMaT—Phase 5 to develop continuous module manufacturing technology.

**Status/Accomplishments:** A major goal (originally for 1999) in crystal growth has already been attained and is now being fully implemented—namely an improved string material which increases run lengths and reduces hot zone parts costs.

**Planned FY 1999 Milestones:** Redesign of crystal growth system, robotic load and unload in cells, redesign of cell equipment for doubled throughput, continuous glass etch process.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Manufacturing Cost and Throughput Improvements for CIGS-based Thin Film PV Modules

| **Contract #:** ZAX-8-17647-11 | **Contract Period:** 7/7/98–9/6/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Global Solar Energy<br>12407 W. 49th Avenue<br>Wheat Ridge, CO 80033 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>S. Wiedeman<br>**Phone:** 520-546-6313 **Fax:** 520-546-6318 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Global Solar Energy |
| | **DOE Funding Allocation:**<br>1998: $ 489,000 | **Cost Share Funding:**<br>1998: $ 230,119 |

**Project Objective:** The objective of this subcontract over its three-year duration is to the advance the Global Solar PV manufacturing technologies through the: development of equipment and processes for high-speed module scribing of the layers of CIGS based PV modules deposited on flexible substrates; development, adaptation, and optimization of commercial ink-jet equipment as a replacement for screen printing methods for high-speed, large-area thin-film PV module fabrication on a flexible substrates; development of uniform, high rate (27 cm/min) absorber deposition processes for flexible substrates with high materials utilization; development of a novel, non-contact, non-destructive diagnostic technique for the physical and electronic assessment of thin-film CIGS absorber layers in manufacturing line production; and the development of a replacement option for their molybdenum back contact.

**Approach/Background:** Global Solar Energy will accomplish these objectives by: refining an all-laser, multiple-beam, high-speed (23 cm/sec)scribing method for all CIGS PV layers; developing a process for ink-jet printing as a replacement to screen printing for insulating scribed areas, and integration of this process, along with the laser scribing methods, into the manufacturing production line; developing and integrating a high-rate CIGS deposition process for a moving flexible substrate onto their manufacturing line; designing, assembling, and optimizing a Parallel Detector Spectroscopic Ellipsometer (PDSE) for transfer onto the thin-film CIGS production line; and developing an alternative back contact material that is compatible with CIGS processing on flexible substrate.

**Status/Accomplishments:** None – This subcontract has just been initiated.

**Planned FY 1999 Milestones:** Complete the design and assembly of production laser scribing equipment, and evaluate the front- and back-contact scribe laser/material interaction and the interconnect scribe quality; complete the installation and integration of ink-jet equipment into production scribing equipment; complete the installation of Cu, In, and Ga sources, the redesign and installation of Se containment components, and their operational verification; and complete the selection of the most promising back contact material based on physical properties, cost and minimal loss in efficiency.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

***Major Articles Published in FY 1998:***
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# PVMaT Monolithic a-Si Modules on Continuous Polymer Substrates

| **Contract #:** ZAF-5-14271-4 | **Contract Period**: 7/5/95–2/28/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Iowa Thin Film Technologies<br>2501 North Loop Drive<br>Ames, Iowa 50010 | |
| | **Organization Type**: IN | **Congressional District:** 3 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>F. Jeffrey<br>**Phone:** 515-292-7606 **Fax:** 515-294-9584 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Iowa Thin Film Technologies |
| | **DOE Funding Allocation:**<br>1995: $ 937,375 1997: $ 697,781<br>1996: $ 265,000 1998: $ 605,553 | **Cost Share Funding:**<br>1995: $ 890,000 1997: $ 000,000<br>1996: $ 86,392 1998: $ 197,414 |

**Project Objective:** Advance Iowa Thin Film Technologies' manufacturing technology through manufacturing process research and development in order to reduce module manufacturing costs on the ITFT production line by 68%, increase a-Si module performance, and provide the groundwork for expansion of their production capacity.

**Approach/Background:** Iowa Thin Film Technologies will meet these objectives by increasing the throughput of their metalization, a-Si deposition, and laser-scribing and welding processes.

**Status/Accomplishments:** Implemented a roll based encapsulation process resulting in a 600% increase in throughput for that step and a 90% decrease in lamination materials cost. Implemented automated busbar placement resulting in a 300% increase in throughput for that step. Improved ZnO deposition throughput by another 33%.

**Planned FY 1999 Milestones:** Demonstrate metalization system functioning in a single pass 2-ft/minute. Make decision for future implementation of laser operation alternatives. Demonstrate a 1-$ft^2$ Iowa Thin Film Technologies module fabricated on 0.5 mil substrate. Demonstrate a representative full Iowa Thin Film Technologies module laminate structure. Complete analysis including process times and cost of the step-by-step fabrication of 1-$ft^2$ Iowa Thin Film Technologies modules using the PVMaT developed process technology.

**Major Reports Published in FY 1998:**

Jeffrey, F., Photovoltaic Manufacturing Technology Monolithic a-Si Modules on Continuous Polymer Substrate*," PVMaT Annual Subcontract Report,* NREL/SR-520-25236 (August 1998).
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**

*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Manufacturing and System Integration Improvements for One- and Two-Kilowatt Residential PV Inverters

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| **Contract#:** ZAX-8-17647-08 | **Contract Period:** 7/98–6/00 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Omnion Power Engineering Corporation<br>P.O. Box 879, 2010 Energy Drive<br>East Troy, WI 53120 | |
| | **Organization Type:** IN | **Congressional District:** 1 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>D. Porter<br>**Phone:** 414-642-7200 **Fax:** 414-642-7760 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone:** 303-384-6400<br>**Fax:** 303-384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>Omnion Power Engineering Corporation |
| | **DOE Funding Allocation:**<br>1998: $96,000 | **Cost Share Funding:**<br>1998: $41,143 |

**Project Objective:** The objective of this subcontract over its two-year duration is to produce two residential inverter products that are easily manufactured, and are suitable for use in rooftop residential PV applications. Omnion and its team members will evolve designs and evaluate one-kilowatt and two-kilowatt (kW) single-phase inverters for utility-interconnected applications suitable for high-volume production (5,000 units/year). Omnion continues to use transformerless phase-leg topology, with modifications to broaden the input voltage range to 180 to 500 Vdc. The new approach will result in a lighter, more efficient, lower cost solution for one-kilowatt and two-kilowatt inverters.

**Approach/Background:** Omnion has been building small inverters in the range of 2 to 6 kW for many years. The market seems to be changing to where the higher power systems are not as popular as lower power systems. Since cost is determined by the size of the largest system for a multiple size design, more cost-effective systems can be produced by targeting the 1 and 2 kW sized systems.

**Status/Accomplishments:** The contract was started late in FY 1998. Testing of various inductor designs has been done and the design of a buck-boost section of the inverter was started.

**Planned FY 1999 Milestones:** Build prototypes for testing, design preproduction models, and design and test the production capability.

**Major Reports Published in FY 1998**: NA

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Three Phase Power Conversion System for Utility Interconnected PV Applications

| **Contract#:** ZAF-14271-02 | **Contract Period:** 9/96–12/98 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Omnion Power Engineering Corporation<br>P.O. Box 879, 2010 Energy Drive<br>East Troy, WI 53120 | |
| | **Organization Type:** IN | **Congressional District:** 1 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>D. Porter<br>**Phone:** 414-642-7200 **Fax:** 414-642-7760 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone:** 303-384-6400<br>**Fax:** 303-384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>Omnion Power Engineering Corporation |
| | **DOE Funding Allocation:**<br>1995: $371,873 1997: $258,458<br>1996: $0 1998: $142,127 | **Cost Share Funding:**<br>1995: $98,852 1997: $127,777<br>1996: $67,131 1998: $0 |

**Project Objective:** Omnion has three main goals for the work. The first is to improve its power conversion system (PCS) Manufacturing process. The second is to reduce the manufacturing cost by moving to a point design concept. Finally, we want to lay the groundwork for increased production.

**Approach/Background:** Omnion has been producing three phase power conversion for the utility interconnected market for many years. When the project started, Omnion was selling a modular system designed to PVUSA specifications. This was no longer a cost-effective solution because of features that no longer were necessary to the market custom engineering costs.

**Status/Accomplishments:** Omnion has completed the pre-production Series 3300 inverter. It has been manufactured using new methods that reduce the labor by 50% and reduces the material cost by 50%. Cost was reduced by simplifying the design. This will result in a more reliable system. The inverter makes use of better packaging of the Insulated Gate Bipolar Transistors (IGBTs) that were developed for the motor drive industry. The new packaging allows the same IGBT to produce more current at the same junction temperature. This is done by better thermal design. The Pre-Production unit will undergo testing at Sandia National Laboratories.

**Planned FY 1999 Milestones:** In FY 1999, we will finish the contract with a final review meeting and the final report.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report,* NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Manufacturing of the PVI Power Grid

| **Contract #:** ZAF-5-14271-11 | **Contract Period**: 10/27/95 – 2/8/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Photovoltaics International<br>171 Commercial Street<br>Sunnyvale, CA 94086 | |
| | **Organization Type**: IN | **Congressional District:** 14 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>W. Bottenberg<br>**Phone:** 408-746-3062 x207 **Fax:** 408-746-3890 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Photovoltaics International |
| | **DOE Funding Allocation:**<br>1995: $ 248,500 1997: $1,085,000<br>1996: $1,072,447 1998: $ 956,402 | **Cost Share Funding:**<br>1995: $ 106,500 1997: $ 465,000<br>1996: $ 459,620 1998: $ 409,887 |

**Project Objective:** Advance Photovoltaics International manufacturing technology through manufacturing process research and development in order to reduce its linear concentrator module manufacturing costs to $2.00/Watt, increase module performance, and provide the groundwork for expansion of its production capacity to 50 MW/yr.

**Approach/Background:** Photovoltaics International will meet these objectives by developing a high-volume (50 MW/yr) production technology for extruded lenses, a (25 MW/yr) high-volume technology for the production of module sides panels and endcaps, a parallel-process for automated receiver assembly, a roll-forming technology for the fabrication of panel frame members, and the elimination of volatile organic materials in receiver fabrication and for bonding plastic collector components without solvent adhesives.

**Status/Accomplishments:** Redesigned collector to take advantage of roll forming technology for side fabrication and die cast technology for metal end caps. Tooling was ordered for all collector parts. Prototype collectors were assembled and mounted in a roof-top configuration on the new roll-form frame. Developed a high volume process and machine for encapsulating cells in the receivers using EVA. Developed required tooling and workstations for self-aligned assembly of collectors. Eliminated usage of all volatile organic materials in collector assembly.

**Planned FY 1999 Milestones:** Complete a one-month manufacturing run demonstrating high-volume (50 MW/yr) production technology for extruded lenses and (25 MW/yr) high-volume technology for the production of module sides panels and endcaps meeting project cost goals. Deliver a sample of a lens manufactured using the closed-loop process and demonstrating 0.5% consistency in lens profile. Deliver samples of revised collector with roll formed metal sides and metal endcaps manufactured using the new process.

**Major Reports Published in FY 1998:**
NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).*

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# PowerGuard® Advanced Manufacturing

| **Contract #:** ZAX-8-17647-12 | **Contract Period:** 6/10/98–6/00 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | PowerLight Corporation<br>2954 San Pablo Avenue<br>Berkeley, CA 94710 | |
| | **Organization Type**: IN | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>Thomas Dinwoodie<br>**Phone:** 510-540-0550 x227 **Fax:** 510-540-0552 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>PowerLight Corporation |
| | **DOE Funding Allocation:**<br>1998: $275,000 | **Cost Share Funding:**<br>1998: $310,106 |

**Project Objective:** The objective of this sub-contract over its three year lifetime is to continue the advancement of PowerLight Corporation PV manufacturing technologies in order to reduce cost and increase manufacturing capabilities. PowerLight will demonstrate system costs of $3.05/W and complete manufacturing improvements for PowerGuard tile fabrication capability of 16 MW/yr, and stimulate US PV laminate manufacturing expansion to 2 MW/year.

**Approach/Background:** The approach is to introduce incremental improvements to PowerLight's system components and manufacturing processes to reduce Balance of System (BOS) costs. PowerLight will address PowerGuard system cost reduction through 1) improvements in manufacturing technology related to system (non-module) components, 2) product design enhancements, 3) increased production capacity, 4) enhanced system reliability, and 5) strategic alliances to leverage PV module technical improvements.

**Status/Accomplishments:** PowerLight reviewed and documented all State and Federal standards and regulations which are applicable to a PV manufacturing facility. The assembly layout master plan was mostly complete by the end of fiscal year '98. This plan entails PowerLight's strategic direction, proposed plant and equipment advancements, an equipment budget analysis, and production costing. PowerLight initiated the installation of a commercial demonstration of its PowerGuard product for the New York Power Authority (NYPA). The manufacturing of the systems installed for NYPA utilized some of the preliminary advances made in Sloped Tile Assembly and RT PowerCurb, and provided an invaluable testing ground for other proposed manufacturing enhancements. Wind Tunnel testing has been initiated and has yielded useful design information.

**Planned FY 1999 Milestones:**

PowerLight will complete the design and assessment of XPS Processing, Coating, Flat Tile Spacer Attachment, J-Box and Electrical Quick Connect manufacturing stations, design, construct prototypes incorporating the advancements in PowerGuard design, complete construction of a-Si Millennium prototype PowerGuard roof tiles, initiate UL and foreign markets certification and jointly initiate construction of a 40kW commercial system utilizing improvements under this program.

**Major Reports Published in FY 1998:**

*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**

*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

# Photovoltaic Cz Silicon Module Improvements

| **Contract #:** ZAF-6-14271-12 | **Contract Period:** 11/9/95 – 1/23/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Siemens Solar Industries<br>P.O. Box 6032<br>4650 Adohr Lane<br>Camarillo, CA 93011 | |
| | **Organization Type**: IN | **Congressional District:** 23 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>R. King<br>**Phone:** 805-388-6263 **Fax:** 805-388-6557 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Siemens Solar Industries |
| | **DOE Funding Allocation:**<br>1995: $ 422,663 1997: $ 845,326<br>1996: $ 845,326 1998: $ 864,010 | **Cost Share Funding:**<br>1995: $ 422,663 1997: $ 845,326<br>1996: $ 845,326 1998: $ 864,010 |

**Project Objective:** Advance Siemens Solar Industries' Czochralski (Cz) crystalline silicon (c-Si) module manufacturing technology through manufacturing process research and development in order to reduce module production costs by 18%. Increase the average module performance off the manufacturing line, and identify and evaluate modifications that will expand Siemens Solar Industries' commercial production capacities.

**Approach/Background:** Siemens Solar Industries will meet these objectives by identifying alternative Cz c-Si module designs, material sources and processes which lower module component cost and by increasing manufacturing process yields by 15%, reducing labor costs in Cz module manufacturing, and increasing productivity by 15%.

**Status/Accomplishments:** Siemens Solar Industries has fully implemented production of 150-mm cell and module products at 10% of SSI's total production volume. This will lead to the 18% reduction in cost and improvement in productivity as planned in the program. SPC has been implemented in wafering, critical cell fabrication steps and in soldering yields. Thinner cutting wire has been implemented at a cost savings of $400K per year. A cost effective BSF process has been demonstrated with Aluminum backed cells at a 6-7% relative efficiency gain.

**Planned FY 1999 Milestones**: None–the program ends in November 1998

**Major Reports Published in FY 1998:**

Jester, T.L., *"Photovoltaic Cz Silicon Module Improvements," PVMaT Annual Subcontract Report,* NREL/SR-520-25269 (September, 1998).
NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).*

**Major Articles Published in FY 1998:**

*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)
*Eighth Workshop on Crystalline Silicon Solar Cell Materials and Processes, Copper Mountain, CO, 1998* NREL Publications

# Specific R&D Problems in Product Manufacturing

| **Contract #:** ZAX-8-17647-14 | **Contract Period:** 6/22/98–8/21/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Siemens Solar Industries<br>P.O. Box 6032<br>4650 Adohr Lane<br>Camarillo, CA 93011 | |
| | **Organization Type**: IN | **Congressional District:** 23 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>T. Jester<br>**Phone:** 805-388-6500 **Fax:** 805-388-6557 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Siemens Solar Industries |
| | **DOE Funding Allocation:**<br>1998: $ 626,000 | **Cost Share Funding:**<br>1998: $ 626,000 |

**Project Objective:** The objective of this subcontract over its three year duration is to continue the advancement of Siemens PV manufacturing technologies in order to develop and optimize silicon ingot growth, wafer sawing, and solar cell processes (which are necessary to manufacture 125-micron wafers and cells), as well as crystal growth processes for the production of 200 mm diameter Cz silicon ingots. Additionally, Siemens shall develop improved modules using the new 200 mm diameter cells, and develop and optimize processes for the reduction, and re-use of waste material from both the Siemens wafer and cell manufacturing processes.

**Approach/Background:** Siemens Solar Industries will meet these objectives by: developing and integrating new optimized cell fabrication processes into their manufacturing line for the production of 17% efficient, 125µm cells with a 30% reduction in the cell manufacturing cost; developing a large-area cell production capability for 200mm diameter, 4.5-watt prototype solar cells and low-cost prototype modules to reduce module manufacturing cost by 20%; and initiate Siemens' Environmental, Safety and Health activities directed toward reducing their hazardous waste by over 50% through recycling and re-use of slurry materials in their wire saw process and an over 70% reduction in caustic waste.

**Status/Accomplishments**: None – This subcontract has just been initiated.

**Planned FY 1999 Milestones**: Complete development of a pilot crystal growth process for quality ingots to be wire-sawn into 150-micron wafers and producing 125-micron (16% efficient) solar cells; complete the preliminary investigation of viable technical options for auto-boating 150-micron wafers and initiation of design phase; development a pilot process and verify environmental stability for fabrication of 25-micron thick BSF solar cells; demonstrate the growth of 200-mm diameter Cz silicon ingots, as well as the slicing of wafers (with a 5% reduction in manufacturing costs) and the fabrication of cells (3.9 watt) from these ingots; demonstrate the separation of SiC from the slurry mix and the effective use of this recycled SiC in the wafer slicing process; and complete implementation of SiC recycling process in pilot production.

**Major Reports Published in FY 1998:**
NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).*

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# High Throughput Manufacturing of Thin Film CdTe Photovoltaic Modules

| **Contract #:** ZAI-4-11294-2 | **Contract Period:** 11/16/93-3/15/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Solar Cells, Inc.<br>1702 North Westwood Ave.<br>Toledo, Ohio 43607 | |
| | **Organization Type**: IN | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>D. Sandwisch<br>**Phone:** 419-534-3377 **Fax:** 419-534-2794 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solar Cells, Inc. |
| | **DOE Funding Allocation:**<br>1994: $1,189,385 1997: $1,051,391<br>1995: $ 100,000 1998: $ 290,230<br>1996: $ 500,000 | **Cost Share Funding:**<br>1994: $1,189,385 1997: $ 463,363<br>1995: $ 100,000 1998: $1,596,831<br>1996: $ 214,286 |

**Project Objective:** Advance Solar Cells, Inc.'s PV manufacturing technologies through manufacturing process research and development in order to reduce module production costs, increase CdTe module performance, and provide the groundwork for expansion of SCI's commercial production capacities.

**Approach/Background:** The objectives shall be met by designing, debugging, and operating a multimegawatt/year automated, continuous PV manufacturing line that produces 60cm x 120cm thin-film CdTe coated plate and modules.

**Status/Accomplishments:** Achieved a 250-plates/week and 100-modules/week production rate on the 100kW pilot production line and some equipment installed for the 20MW manufacturing line, demonstrated weekly yield of greater than 90% and decreased standard variation to plus or minus 10% for production activities using the new quality assurance program, demonstrated a 7.5% average module efficiency for modules manufactured using multi-megawatt deposition equipment and pilot production line, and continued mechanical assembly of the advanced high-throughput deposition system.

**Planned FY 1999 Milestones:** Complete a multi-megawatt plate manufacturing line using improvements and enhancements developed through Solar Cells, Inc.'s PVMaT efforts. Complete assembly, debug, and startup of advanced high-throughput deposition system. Integrate manufacturing management system for highly productive and efficient operations.

**Major Reports Published in FY 1998:**

Sandwisch, D.W., *"High Throughput Manufacturing of Thin Film CdTe Photovoltaic Modules," PVMaT Annual Subcontract Report,* NREL/SR-520-25263 (August, 1998).
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**

*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Specific PVMaT R&D in CdTe Product Manufacturing

| **Contract #:** ZAX-8-17647-06 | **Contract Period:** 5/8/98–7/7/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Solar Cells, Inc.<br>1702 North Westwood Ave.<br>Toledo, Ohio 43607 | |
| | **Organization Type**: IN | **Congressional District:** 9 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>D. Sandwisch<br>**Phone:** 419-534-3377 **Fax:** 419-534-2794 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solar Cells, Inc. |
| | **DOE Funding Allocation:**<br>1998: $ 682,000 | **Cost Share Funding:**<br>1998: $ 307,410 |

**Project Objective:** The objective of this subcontract over its three-year duration is to continue the advancement of the Solar Cells, Inc. manufacturing technologies in order to: develop high-throughput, low-cost processes for the lamination, potting and laser scribing portions of the Solar Cells, Inc. CdTe module manufacturing line; improve acceptance of Solar Cells, Inc. products into existing and new markets and improve the acceptance and variety of the Solar Cells, Inc. product line to provide an opportunity to penetrate market segments other than those which are served by its standard frameless, 60cm x 120cm module; and establish a safety, health and environmental program which will place Solar Cells, Inc. in a leadership position relative to comparable businesses both within and outside of the photovoltaic industry

**Approach/Background:** Solar Cells, Inc. will accomplish these objectives by: developing low-cost lamination processes with throughputs raised from 18 modules/hour to at least 30-modules/hour while simultaneously reducing labor costs by 50% and lowering capital requirements by a factor of four; developing high-throughput, low cost potting by increasing potting line throughput by a factor of at least four, reducing labor costs by at least a factor of ten, and increasing overall quality; developing improved laser scribing techniques and equipment by engaging industry experts and vendors to implement state-of-the-art techniques and automation (New scribing techniques will result in scalability to 60 modules an hour with the potential of exceeding that capacity with nominal upgrades); certifying Solar Cells, Inc. modules according to IEEE 1262 and UL 1703 in three successive, evolutionary steps depending on product changes due to market demand and product changes; Refining and improving environmental, health and safety programs including use of external industry experts leading to ISO 14,000 certification and implementation of best-demonstrated-practices of world class programs.

**Status/Accomplishments:** None – This subcontract has just been initiated.

**Planned FY 1999 Milestones:** Complete lamination, potting and laser equipment and process upgrades achieving throughputs scalable to 60-modules/hour, obtain UL and PowerMark Corporation certifications for Solar Cells, Inc.'s current and planned module products and obtain ISO 14,000 certification for Solar Cells, Inc.'s best-demonstrated-practices environmental, health and safety program.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

***Major Articles Published in FY 1998:***
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

## PVMaT

# Development of Standardized, Low-Cost AC PV Systems

| **Contract #:** ZAF-5-14271-01 | **Contract Period:** 9/8/95–6/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Solar Design Associates, Inc.<br>P.O. Box 242<br>Harvard, MA 01451-0242 | |
| | **Organization Type**: IN | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator:**<br>S.J. Strong<br>**Phone:** 978-456-6855 **Fax:** 978-456-3030 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solar Design Associates, Inc. |
| | **DOE Funding Allocation:**<br>1995: $444,858 1997: $145,809<br>1996: $68,000 1998: $58,530 | **Cost Share Funding:**<br>1995: $155,700 1997: $51,034<br>1996: $23,800 1998: $19,926 |

**Project Objective:** Solar Design Associates, Inc. (SDA), of Harvard, MA and Solarex Corporation, of Frederick, MD, teamed together to propose a multi-level program under PVMaT Phase 4-A1 targeted at design innovation, standardization and modularity to deliver low-cost AC PV systems to the utility-interactive market.

**Approach/Background:** The Team proposed to work in the following six areas key in this PVMaT Phase 4-A1 program: A System-level Review of PV Systems Components, Design & Installation; 2/ Innovative Mounting Systems, 3/ Enhanced Modular Inverters, called Mircro-inverters; 4/ Pre-manufactured Wiring Systems; 5/ Standardized, Pre-approved, Modular Designs–The Kit Approach 6/ US PV Products and Systems for Export. The work was divided into two one-year Phases. Each of the six major work tasks were divided into two phases to match the two-year format of the effort.

**Status/Accomplishments:** The Microinverter achieved UL listing and FM certification. Another significant result of this work supported under PVMaT is that Solarex has filed a US patent application on the new module frame and mounting system. The patent application is US Utility Patent # 09/123,724 for: "Photovoltaic Module Framing System with Integral Electrical Raceways". Solarex has already started to manufacture this new combination framing and array mounting system and a number of residential scale installations are already in place in the field.

**Planned FY 1999 Milestones:** Complete the final revisions to the draft final report to incorporate comments and input from the NREL PVMaT Technical Monitoring Team and then submit the (final) Final Report for publication.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*Strong, Steven J., "Photovoltaic Systems in the Built Environment–A Review of International Technologies and Applications" Advances in Solar Energy, Volume 12, American Solar Energy Society, 1998, ISBN 0731-8618, ISBN 0-89553-255-7*

# Design, Fabrication, and Certification of Advanced Modular PV Power Systems

| **Contract #:** ZAF-5-14271-07 | **Contract Period:** 9/8/95–6/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | E.A. Padula Lumber Co., Inc. dba Solar Electric Specialties<br>P.O. Box 537<br>Willits, CA 95490 | |
| | **Organization Type**: IN | **Congressional District:** 1 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Glen Minyard<br>**Phone:** 707-459-9496 **Fax:** 707-459-5132 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 0303-380-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solar Electric Specialties |
| | **DOE Funding Allocation:**<br>1995: $155,210 1997: $0<br>1996: $84,962 1998: $0 | **Cost Share Funding:**<br>1995: $38,802 1997: $0<br>1996: $21,241 1998: $0 |

**Project Objective:** The objective of this subcontract is to develop prototype products that are certified, standardized, pre-engineered product lines, MAPPS and Photogensets. The two systems incorporate technical innovations, low-cost-manufacturing techniques, and are designed to be UL-certified. SES expects these products to provide the basis for future commercial product lines of standardized packaged systems.

**Approach/Background:** The Solar Electric approach is to design integrated PV systems to significantly reduce the installed system life cycle costs to the PV customer. They are developing fully-designed and engineered systems that will be submitted for UL listing, and are conducting research and development for novel or improved components to improve performance and reliability.

**Status/Accomplishments:** Completed development and definition of manufacturing processes for two remote PV power systems; a modular autonomous power supply (MAPPS) with full UL and FM listing and a trailer-mounted 1-kw Photgenset. This unit is a hybrid portable power system incorporating PV, a propane generator and a large battery bank to provide continuous AC power in emergency and remote applications.

**Planned FY 1999 Milestones:** N/A

**Major Reports Published in FY 1998:**
Lambarski, T., and Minyard, G. "Design, Fabrication, and Certification of Advanced Modular PV Power Systems–Final Technical Progress Report," October 1998 NREL/SR-520-24921

**Major Articles Published in FY 1998:**

# Improvements in Polycrystalline Silicon PV Module Manufacturing Technology

| **Contract #:** ZAX-8-17647-05 | **Contract Period:** 5/4/98–7/3/01 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Solarex<br>630 Solarex Court<br>Frederick, MD 21701 | |
| | **Organization Type**: IN | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator**<br>J. Wohlgemuth<br>**Phone:** 301-698-4375 **Fax:** 301-698-4201 | |
| **Technical Monitor:**<br>R. Mitchell<br>**Phone**: 303-384-6479<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Solarex |
| | **DOE Funding Allocation:**<br>1998: $ 561,000 | **Cost Share Funding:**<br>1998: $ 489,184 |

**Project Objective:** The objective of this subcontract over its three year duration is to continue the advancement of Solarex PV manufacturing technologies in order to design and implement a process which produces polycrystalline silicon PV modules that can be sold profitably for $2.00 per peak watt or less and which increases the production capacity of the Frederick plant to at least 25MW/megawatts per year.

**Approach/Background:** To accomplish these goals Solarex will focus their efforts on: developing a process to produce silicon feedstock from commercial grade $H_2SiF_6$ that can be sold profitably for less than $15/kilogram in large quantities to industrial Silicon PV manufacturers, improving the control of their casting process to increase yields and improve material quality through a new automated casting control system; reducing their wire saw center-to-center cut distance to less than 450mm in production, developing a glycol-based slurry system that does not require organic cleaners and eliminates the generation of hazardous waste material; developing a method to recycle a significant fraction of their silicon carbide grit; demonstrating and implementing a cost-effective, robust cell process that produces a minimum average cell efficiency of 15% and improves the cell line electrical yield; developing and qualifying an encapsulation system that meets technical and reliability requirements and can be laminated and cured in less than 6 minutes in the present Solarex laminators; refining three specific production line process areas for improved product and materials handling to increase production line yield and reduce labor; improving process measurement and control in their production line and reduce rework through the implementation of an improved information system, and developing and implementing a brick identification system.

**Status/Accomplishments:** Accomplishments during 1998 include: development and implementation of a new process control system on one set of casting stations; introduction and qualification of thinner wire for wafering; and identification of a silicon nitride process that produces 15% efficient large area polycrystalline cells.

**Planned FY 1999 Milestones:** Complete laboratory verification of process to produce Si feedstock from $H_2SiF_6$ and use this feedstock in the Solarex process to make solar cells; complete installation of new automated casting control system on all stations; complete process development for SiC recycle and transfer to production; complete qualification of the silicon nitride process and modules made using these cells; select at least one fast cure encapsulant, develop processing procedures, initiate outdoor testing and complete accelerated environmental testing; and complete development of Brick Identification system and implement as appropriate.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press)

# Post-Lamination Manufacturing Process Automation for Photovoltaic Modules

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| **Contract #:** ZAX-8-17647-04 | **Contract Period:** 4/15/98–6/15/01 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Spire Corporation<br>One Patriots Park<br>Bedford, MA 01730-2396 | |
| | **Organization Type**: IN | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Michael J. Nowlan<br>**Phone:** 781-275-6000 x327 **Fax:** 781-275-7470 | |
| **Technical Monitor:**<br>M. Symko-Davies<br>**Phone**: 303-384-6528<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1998: $454,561 | **Cost Share Funding:**<br>1998: $194,812 |

**Project Objective:** Spire Corporation is addressing the Photovoltaic Manufacturing Technology (PVMaT) project goals of PV module cost reduction and improved PV module manufacturing process technology. New cost-effective automation processes are being developed for PV module assembly after the solar cell lamination process. The development and implementation of these automated systems are expected to result in significant labor cost savings and increased throughput.

**Approach/Background:** The automated processes under development in this program include (1) a module buffer storage system, including conveyor load/unload and module storage, (2) an integrated edge process system, combining automated edge trimming, edge sealing, and framing capabilities, (3) a junction box installation system for attaching a junction box, and (4) an integrated module test system that combines high voltage isolation testing, ground continuity testing, and module performance testing. Proof-of-concept prototype systems will be developed and evaluated with module components from several US module manufacturers.

**Status/Accomplishments:** A survey of PV module manufacturers was completed to identify current industry practices and to determine the requirements for the automated systems being developed in this program. Survey data and data gathered during site visits to module manufacturers was used to define system capabilities and specifications for post-lamination automation processes. Top-level designs were generated for a module buffer storage system and an integrated module test system. Detailed mechanical and electrical design work is underway for the buffer storage system. Process development work is in progress for module edge trimming and edge sealing.

**Planned FY 1999 Milestones:** Prototype automation systems will be developed and tested for module buffer storage and integrated module testing systems. Both systems will be evaluated with module components from several US module manufacturers. The buffer storage system will transfer laminates or modules from a conveyor to a cart and back again, as required. The test system will align and probe modules for high voltage and ground tests, and transport laminates or modules through a sun simulator for measuring current-voltage curves. Module edge trimming, edge sealing, and framing processes will be developed and an integrated system that combines these processes will be defined.

**Major Reports Published in FY 1998:**

M. J. Nowlan and W. G. Kurth, "A Summary Report on: Design Definition for Post-Lamination Process Automation for Photovoltaic Modules," Spire Corp. document No. Design-10182, 1998.

**Major Articles Published in FY 1998:**

M. J. Nowlan, W.G. Kurth, T.D. Harmon, T.W. McCormick, J.M. Murach, W.F. Breen, S.J. Hogan, M.R. Diver, M.I. Symko, and S.R. Rummel, "A Photovoltaic Industry Survey on Post-Lamination Module Manufacturing," *NCPV Photovoltaics Program Review; Proceedings of the 15th Conference,* Denver, CO, 1998; AIP Conference Proceedings (in press).

# Advanced Development of PV Encapsulants

| **Contract #:** ZAG-3-11219-02-105 | **Contract Period:** 12/30/92–3/31/97 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | STR (Springborn Testing and Research)<br>10 Water Street<br>Enfield, CT 06082-4899 | |
| | **Organization Type**: IN | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>W. Holley<br>**Phone:** 860-749-8371 **Fax:** 860-749-8234 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>STR |
| | **DOE Funding Allocation:**<br>1994: $144,750 1997: ( $40,000)<br>1995: $312,451 1998: $0<br>1996: $0 | **Cost Share Funding:**<br>1994: $62,036 1997: ($17,143)<br>1995: $133,909 1998: $0<br>1996: $0 |

**Project Objective:** The subcontracted Phase III-A research effort will solve degradation problems related to the PV module encapsulant ethylene vinyl acetate (EVA). The objective of this effort is to develop a stabilized PV module encapsulant that has similar extruding and laminating properties to EVA. Furthermore, the improved encapsulant will be comparably priced to EVA with comparable optical properties.

**Approach/Background:** In Phase I, a survey of EVA discoloration and/or degradation case histories was conducted. From that information, a series of Phase II experiments were conducted to determine which variables have the most effect on EVA discoloration and/or degradation mechanisms. In Phase III the most viable candidates were tested and qualified in commercial PV module construction.

**Status/Accomplishments:** New encapsulants have been identified and subjected to accelerated testing. These materials, amenable to current curing practices most module manufacturers, have been deployed for outdoor accelerated tests to confirm performance projections. The Final Report was published.

**Planned FY 1999 Milestones:**

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report,* NREL/BK-210-23607, (June 1998).
W.. W. Holley, S.C. Agro, "Advanced EVA-Based Encapsulants, Final Report January 1993–June 1997," NREL/SR-520-25296

**Major Articles Published in FY 1998:** None.

# 2-kW DC to AC Power Inverter Module for PV Applications

| **Contract #:** ZAF-4-14271-00N | **Contract Period:** 9/8/95–5/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Trace Engineering Co. Inc.<br>5916 195TH NE<br>Arlington, WA 98223 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Christopher Freitas<br>Trace Engineering Co. Inc.<br>**Phone:** 360-435-8826 **Fax:** 360-435-3945 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone**: 303-384-6400<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>Trace Engineering Co. |
| | **DOE Funding Allocation:**<br>1995: $83,716 1997: $0<br>1996: $109,573 1998: $0 | **Cost Share Funding:**<br>1995: $22,254 1997: $0<br>1996: $29,127 1998: $0 |

**Project Objective:** The goal of this research and development contract was to develop and prototype for manufacturing a modular, bi-directional power inverter for photovoltaic applications. This modular inverter will be used as a building block for larger inverters by connecting in parallel (for higher power) or in series (for higher AC voltage) or both. The modular inverter will be capable of being interconnected for single, split and three phase configurations for both 60 hertz (domestic) and 50 hertz ( international) applications. Included in the development effort was a standardized packaging system to allow installation of one or more inverters in indoor or outdoor applications, with and without battery energy storage systems.

**Approach/Background:** Trace Engineering has been manufacturing power inverters for over 13 years and has built more than 300,000 inverters. The increased production volume and expansion of the Trace product line into numerous models and power levels to meet the requirements of the wide range of possible applications has caused Trace to see the need for the development of new inverter designs which could be manufactured more easily, used more flexibly in different applications, and which could achieve higher performance and reliability. This PVMaT subcontract has provided the needed impetus to accelerate those efforts through the development of a modular, bi-directional power inverter which could be used as a "building block" for larger and more complex systems.

The approach followed was to split the efforts into one group focused on the core inverter technology, another on the control and protection issues, and a third on the packaging and system integration issues.

**Status/Accomplishments**: Trace accomplished the following: developed an advanced hardware based protection system for the transistors used in many of Trace's products which resulted in a substantial improvement in the reliability of today's generation of inverters; successfully fielded the system developed to allow connection of several inverters together was successfully fielded in over 50 applications in the US, Australia, Indonesia, South America, Spain and other countries. Several system included four inverters in a parallel/series configuration for 22 kW of continuous power at 120/240 Vac; developed, prototyped, demonstrated a modular inverter packaging system which incorporates multiple inverters and the required balance of systems components for a complete application, and the resulting product, the Trace Power Module system was UL listed in March of 1998; and finally developed, prototyped and have planned for production a reduced cost 2.5 kW version of their popular SW series for use as a modular inverter. The cost reduction were based on ideas developed in this research of other inverter topologies and designs.

**Major Articles Published in FY 1998:** None.

## PVMaT

# Development of a Fully-Integrated PV System for Residential Applications

| | |
|---|---|
| **Contract#:**ZAX-8-17647-02 | **Contract Period:** 03/27/98–07/26/00 |

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Utility Power Group, Inc.<br>9410-G De Soto Ave.<br>Chatsworth, CA 91311-4982 | |
| | **Organization Type:** IN | **Congressional District:** 25 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Richard West<br>**Phone:** 818-700-1995 **Fax:** 818-700-2518 | |
| **Technical Monitor:**<br>H. Thomas<br>**Phone:** 303-384-6400<br>**Fax:** 303-384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>Utility Power Group, Inc. |
| | **DOE Funding Allocation:**<br>1998: $237,900 | **Cost Share Funding:**<br>1998: $101,957 |

**Project Objective:** The overall objective of this subcontract is to reduce the total installed cost and increase the reliability of residential roof top-mounted PV power systems. The secondary objective is to increase US system production and installation capacity. UPG is working to achieve a 30% reduction in total non-module related system costs through the development of a PV Array Power Unit with direct material and direct labor costs below $\$4/ft^2$ and $0.45/W, respectively.

**Approach/Background:** The roof-top system will consist of a PV array, a 4–6 kW Power Unit and an optional Energy Storage Unit, each defined as follows:

PV Array : Includes all PV modules (either crystalline or thin-film), panels, structural support equipment and materials, dc electrical equipment and materials, and installation labor and equipment required to secure and wire the fully functional dc PV array from the roof-top to the input of the Power Unit up to 6 kWdc.

Power Unit: Includes all materials, components, and equipment required to perform all dc-ac/ac-dc power collection, conversion, and control functions from the output of the PV Array to the interconnection to utility service for power ranges from 4–6kW.

Energy Storage Unit: Includes a battery string, and all structural, mechanical, electrical materials and equipment required to provide a source of stored dc energy to be delivered to an input of the Power Unit.

**Status/Accomplishments:**
Utility Power Group completed designing the PV Array structural support, the power/control circuit, and the Energy Storage Unit electro-mechanical design and completed Power Unit electro-mechanical layout.

**Planned FY 1999 Milestones:**
Utility Power Group plans to complete development of prototypes for each component, the PV Array, Power Unit and Energy Storage Unit and submit unit for testing.

**Major Reports Published in FY 1998: none**

**Major Articles Published in FY 1998:**
NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998; AIP Conference Proceedings (in press)

## Module Performance and Reliability

# Collector & Systems Testing Support

| | |
|---|---|
| **Contract #:** 75-3058 and AK-0748A | **Contract Period:** 10/1/95–8/31/99 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | EG&G<br>Albuquerque, NM 87119 | |
| | **Organization Type**: IN | **Congressional District:** 1 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>E. Dawson<br>**Phone:** 505-845-7111 **Fax:** 505-243-1021 | |
| **Technical Monitor:**<br>M. Quintana<br>**Phone**: 505-844-0474<br>**Fax**: 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $230,000<br>1997: $120,000<br>1998: $0 | **Cost Share Funding:** |

**Project Objective:** Provide on-site technical support for module and cell testing and for module durability testing.

**Approach/Background:** Individual provides research and development in the areas of machining, controls, adhesion measurements, electrical and mechanical assembly of test apparatus, performance testing, and computer-aided design.

**Status/Accomplishments:** Contract began in FY98 with accrued costs and no personnel filling available slots. One slot was filled for the period January-September. Most notable accomplishments were studies of Solarex adhesion and solder-joints and developing method to cut tempered glass.

**FY 1999 Milestones:** Contract will be terminated in FY99 due to insufficient funding.

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Module Performance and Reliability

# Collector & Systems Testing Support

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|---|---|
| **Contract #:** AK-0748B | **Contract Period:** 9/1/95–8/31/99 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Spectra Research<br>Albuquerque, NM 87119 | |
| | **Organization Type**: IN | **Congressional District:** 1 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)** | |
| **Technical Monitor:**<br>M. Quintana<br>**Phone**: 505-844-0474<br>**Fax**: 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $325,000<br>1997: $0<br>1998: $4,000 | **Cost Share Funding:** |

**Project Objective:** Provide on-site technical support for module performance testing.

**Approach/Background:** Individual provides computer programming, solar resource measurements, and performance testing, and analysis suport.

**Status/Accomplishments:** Contract carried key personnel for areas of computer programming, resource measurement, and module performance testing.

**FY 1999 Milestones:** Team with Module Performance team members to meet team goals.

**Major Reports Published in FY 1998:** None

**Major Articles Published in FY 1998:** None

## Balance-of-Systems Components Development

# Battery/Controller Development and Systems Support

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|---|---|
| **Contract #:** AP-7660 | **Contract Period:** 9/3/95–12/31/98 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Florida Solar Energy Center<br>Cocoa, FL 32816-0150- | |
| | **Organization Type**: CU | **Congressional District:** 8 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>J. Ventre<br>**Phone:** 407-638-1000 **Fax**: 407-638-101 | |
| **Technical Monitor:**<br>M. Quintana<br>**Phone**: 505-844-0474<br>**Fax**: 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $180,000<br>1997: $350,000<br>1998: $150,000 | **Cost Share Funding:** |

**Project Objective:** Assist Sandia and the U.S. PV industry to identify and study PV module durability issues.

**Approach/Background:** FSEC continues to provide critical support to Sandia and the U.S. PV industry by providing expertise and resources necessary to address module durability. Leveraging this work by taking advantage of Florida University system test facilities and links to think-film as well as crystalline technologies provides exceptional value.

**Status/Accomplishments:** FSEC hosted a symposium attended by personnel from PV manufacturers, national labs, NASA, and FSEC to provide details of module durability studies. FSEC also performed a comprehensive study to determine the value of adhesion measurements as a quality control metric for PV manufacturers.

**FY 1999 Milestones:** Continue module long-term exposure study. Perform adhesion and/or surface characterization studies on twenty-year-old modules from Natural Bridges array. Support NREL and Sandia in collaborative effort to determine the effects of accelerated UV testing on encapsulant adhesion. Increase the database of adhesion measures by adding measurements from at least one manufacturer.

**Major Reports Published in FY 1998:** Proceedings of PV Module Durability and Long-Term Exposure Symposium, February 17-18, 1998. "Comparison of Mechanical Properties of EVA Encapsulant in New and Field-Deployed PV Modules Tensile Testing of EVA Encapsulant Used in PV Modules."

**Major Articles Published in FY 1998:** None.

## Balance-of-Systems Components Development

# Battery/Controller Development and Systems Support

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|---|---|
| **Contract #:** AU-0556 | **Contract Period:** 8/13/96–10/31/99 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Florida Solar Energy Center<br>Cocoa, FL 32816-0150 | |
| | **Organization Type**: CU | **Congressional District:** 8 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Jim Dunlop<br>**Phone**: 407-783-0300 **Fax**: 407-783-2571 | |
| **Technical Monitor:**<br>T. Hund<br>**Phone**: 505-844-8627<br>**Fax**: 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1997: $100,000<br>1998: $100,000 | **Cost Share Funding:** |

**Project Objective:** Support U.S. PV Industry and DOE PV Program personnel.

**Approach/Background:** Test battery performance and charge control algorithms in small stand-alone PV systems. This work is part of DOE's Balance-of-Systems (BOS) development program designed to improve reliability, lower costs, and encourage manufacturer development of improved PV batteries and battery charge controllers.

**Status/Accomplishments:** The Florida Solar Energy Center (FSEC) tested three different valve-regulated lead-acid batteries using their laboratory test facility and the Brevard Community College's COMET walkway lighting systems. The laboratory work included supporting the field tests and verification of IEEE PV battery test procedures. These COMET walkway lighting systems are representative of current system performance and reliability. Test results indicate that reliability problems exist with the PV lighting ballasts and lamps and one of the three batteries tested. Work is now underway to resolve the lighting reliability problems with the manufacturers.

**FY 1999 Milestones:** Publish yearly report on the COMET walkway systems. Report on the PV battery cycle-life test results. Support drafting of an IEEE SCC-21 PV system and battery test procedure.

**Major Reports Published in FY 1998:** PV Battery Charging Workshop at ASES Solar '98.

**Major Articles Published in FY 1998:** None

## Balance-of-Systems Components Development

# Power Electronic Building Block Program

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|---|---|
| **Contract #:** AO-5380 | **Contract Period:** 2/1/95–10/15/98 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | NASA Management Office<br>Jet Propulsion Lab<br>Pasadena, CA 91109- | |
| | **Organization Type**: US | **Congressional District:** 27 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>S. Krauthamer<br>**Phone**: 818-54-7740 **Fax**: 818-393-4272 | |
| **Technical Monitor:**<br>W. I. Bower<br>**Phone**: 505-844-5206<br>**Fax**: 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1995: $105,000 | **Cost Share Funding:** |

**Project Objective:** Support US PV industry and DOE PV Program personnel with Power Electronic Building Block liaison and information transfer.

**Approach/Background:** Participation in the US Navy Power Electronic Building Block Program, information transfer, and education for inverter manufacturers.

**Status/Accomplishments:** Program review presentations to DOE headquarters; PEBB quarterly meetings; vugraphs available.

**FY 1998 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Balance-of-Systems Components Development

# Inverter Reliability

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|---|---|
| **Contract #:** AU-5805A | **Contract Period:** 10/1/96–9/30/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Omnion<br>2010 Energy Drive<br>East Troy, WI 53120-1357 | |
| | **Organization Type**: IN | **Congressional District:** 1 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Dr. H. Meyer<br>**Phone:** 414-642-7200 **Fax:** 414-642-7760 | |
| **Technical Monitor:**<br>R. Bonn<br>**Phone:** 505-844-6710<br>**Fax:** 505-844-2890 | **B&R Code**: EB22 | **Cost Share Information**:<br>Omnion |
| | **DOE Funding Allocation:**<br>1996: $75,000<br>1997: $75,000<br>1998: $200,000 | **Cost Share Funding:**<br>1996: $60,000 |

**Project Objective:** To improve the reliability of fielded PV systems by 1) developing a quality assurance program 2) preliminary development of a systems engineering capability and 3) development of a reliability database.

**Approach/Background:** A major barrier to the implementation of PV systems is a perceived lack of reliability. A majority of the reliability problems in fielded PV systems are directly related to the inverter. It is the intent of this effort to assist inverter manufacturers in the development of in-house management systems to address issues on reliability and quality. This effort will focus on inverter reliability and improved designs.

**Status/Accomplishments:** Established a quality control system and prepared 85 percent of required manufacturing procedures.

**FY 1999 Milestones:** Complete ISO 9000 quality preparedness and successfully complete the ISO 9000 certification process.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Balance-of-Systems Components Development

# Reliability Program Development

| | |
|---|---|
| **Contract #:** AU-5805B | **Contract Period:** 10/1/96–3/30/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Trace Engineering<br>5916 195th Street, NE<br>Arlington, WA 98223 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>C. Frietas<br>**Phone:** 360-435-8826 **Fax:** 360-435-2239 | |
| **Technical Monitor:**<br>R. Bonn<br>**Phone:** 505-844-6710<br>**Fax:** 505-844-2890 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $75,000<br>1997: $75,000<br>1998: $150,000 | **Cost Share Funding:** |

**Project Objective:** To improve the reliability of fielded PV systems. This project consists of three components 1) development of a quality assurance program 2) development of systems engineering capability and 3) development of a reliability database.

**Approach/Background:** This effort will focus on improving inverter reliability through an in-house management system to address issues on reliability, quality, and improved systems design.

**Status/Accomplishments:** Established a quality control system and prepared 75 percent of required manufacturing procedures. Hired quality inspectors for the Assembly floor.

**FY 1999 Milestones:** Complete ISO 9000 quality preparedness and successfully complete the ISO 9000 certification process.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Balance-of-Systems Components Development

# BOS Testing

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|---|---|
| **Contract #:** AW-8121 | **Contract Period:** 6/9/97–5/11/98 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Utility Power Group<br>9410-G De Soto Ave.<br>Chatsworth, CA 91311-4982 | |
| | **Organization Type**: IN | **Congressional District:** 25 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>R. West<br>**Phone:** 818-700-1995 **Fax:** 818-700-2518 | |
| **Technical Monitor:**<br>R. Bonn<br>**Phone:** 505-844-6710<br>**Fax:** 505-844-28901 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $90,000 | **Cost Share Funding:** |

**Project Objective:** To develop a high efficiency, grid-tied inverter.

**Approach/Background:** Use high frequency switching to decrease magnetic losses and thereby increase efficiency.

**Status/Accomplishments:** Developed a new 2-kW inverter for grid-tied applications.

**FY 1999 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

# SYSTEMS ENGINEERING AND APPLICATIONS

## Systems Performance and Engineering

# PV Interconnection Issues

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|---|---|
| **Contract #:** AS-3621 | **Contract Period:** 2/25/96–2/25/01 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Ascension Technology<br>PO Box 314<br>Lincoln Center, MA 01773 | |
| | **Organization Type**: IN | **Congressional District:** 7 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Ed Kern<br>**Phone:** 781-684-6101 | |
| **Technical Monitor:**<br>J. W. Stevens<br>**Phone:** 505-844-7717<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $16,000<br>1997: $0<br>1998: $4,350.00 | **Cost Share Funding:** |

**Project Objective:** Install grid-tied 30KW inverter for existing PV system. Establish monitoring technique to provide data for reliability project.

**Approach/Background:** Communicate with reliability project leader to determine exact data requirements for reliability project. Configure data monitoring system to provide that information.

**Status/Accomplishments:** Reliability data logged and reported.

**FY 1999 Milestones:** Continue to provide data.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# PV Opportunity Assessment and Projects

| **Contract #:** AM-5277 and AU-5829 | **Contract Period:** 10/1/94–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Bureau of Land Management<br>Utah State BLM<br>Salt Lake City, UT 84145-0155 | |
| | **Organization Type**: US | **Congressional District:** 2 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Trent Duncan<br>**Phone:** 801-539-4090 **Fax:** 801-539-4260 | |
| **Technical Monitor:**<br>H. Post<br>**Phone:** 505-844-2154<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1995: $180,000<br>1996: $200,000<br>1997: $0<br>1998: $0 | **Cost Share Funding:**<br>1995: $180,000<br>1996: $200,000<br>1997: $0 |

**Project Objective:** In partnership with the Bureau of Land Management (BLM) and the DOE, through Sandia National Laboratories, photovoltaic project opportunities are identified and systems are designed and installed.

**Approach/Background:** This contract allows BLM engineers to conduct their own assessments, as well as install pilot projects to gain experience with PV systems. Hardware for these projects is funded by the BLM; therefore, the actual cost-share amount varies. However, the minimum amount of cost-sharing is equal to the amount of DOE funds.

**Status/Accomplishments:** Opportunity assessment completed and published. Over 80 projects completed that have installed PV systems at BLM sites.

**FY 1999 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998:** *Renew the Government: Summary of Projects and Lessons Learned.*

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# Reliability Database

| | |
|---|---|
| **Contract #:** AV-1172 | **Contract Period:** 9/1/96–9/30/98 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Colorado State Energy Office<br>1675 Broadway, Suite 1300<br>Denver, CO 80202-4613- | |
| | **Organization Type:** ST | **Congressional District:** 5 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>M. Roper | |
| **Technical Monitor:**<br>M. Thomas<br>**Phone:** 505-844-1458<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>Colorado State Energy Office |
| | **DOE Funding Allocation:**<br>1996: $15,000<br>1997: $0<br>1998: $0 | **Cost Share Funding:**<br>1994: $45,000 |

**Project Objective:** Define the real life-cycle costs of small PV systems used in recreational development. The database will be published and distributed throughout all of the states.

**Approach/Background:** Partnering with Colorado State Office of Energy Conservation, PV systems installed throughout Colorado are being designed, procured and maintained in a standard manner to assess performance and life-cycle costs.

**Status/Accomplishments:** Results will be part of a presentation at the 1998 Performance and Reliability Workshop.

**FY 1999 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998:** Final report on procurement, lessons learned, and operation and maintenance of small systems.

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# PV Interconnection Issues

| **Contract #:** AU-1225 | **Contract Period:** 8/21/96–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Douglas C. Dawson<br>12193 Califa Street<br>North Hollywood, CA 91607-1102 | |
| | **Organization Type**: IN | **Congressional District:** 26 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Douglas C. Dawson<br>**Phone:** 818-508-8006 **Fax:** 818-752-9240 | |
| **Technical Monitor:**<br>J. W. Stevens<br>**Phone:** 505-844-7717<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $25,000<br>1997: $0<br>1998: $25,000 | **Cost Share Funding:** |

**Project Objective:** Survey Electric Utility Industry Protective Relaying engineers for the writing of an IEEE PV-utility interconnection standard. Provide both an analysis of survey results and perspective of needed protective measures.

**Approach/Background:** Survey existing utility interconnection standards and discuss details of these standards with utility engineers to determine sensitivities. Prepare report on project and assist in getting standard approved.

**Status/Accomplishments:** Provided liaison between P929 working group and IEEE PSRC to help ensure IEEE approval of P929.

**FY 1999 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998:** Contractor report summarized in Sandia's Photovoltaics Quarterly Report.

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# Field Module Durability and System Rating

| **Contract #:** AP-1182 | **Contract Period:** 9/6/95–10/1/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Endecon Engineering<br>3160 Old Crow Canyon, Ste. 240<br>San Ramon, CA 94583- | |
| | **Organization Type**: IN | **Congressional District**: 10 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Chuck Whitaker<br>**Phone:** 510-867-3360 | |
| **Technical Monitor:**<br>D. King<br>**Phone**: 505-844-8220<br>**Fax**: 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $75,000<br>1997: $0<br>1998: $130,000 | **Cost Share Funding:** |

**Project Objective:** Verify systems performance acceptance testing procedures and motivate standard test methods for field testing.

**Approach/Background:** Extensive experience in field testing of large PV arrays and PV systems is available through contractor.

**Status/Accomplishments:** Participated in development of IEEE 1479 standard for module energy rating. Assisted Sandia in field evaluation of PV systems and validation of new system performance models. Experimentally evaluated relative measurement accuracy of low-cost silicon photo diode pyranometer compared to standard instruments. Evaluated repeatability and accuracy of wet resistance test used in field acceptance testing of PV arrays. Evaluated relative accuracy of two models (Perez and HOKR) used for calculating solar irradiance during PV system design/sizing. End-of-contract reports summarizing results to follow.

**FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:** End-of-contract summary reports.

**Major Articles Published in FY 1998:** Whitaker, C., et al. "Application and Validation of a New PV Performance Characterization Method."

## Systems Performance and Engineering

# SERES Field Evaluation, Novel Roof Top System Development, and Disaster Relief Assistance

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|---|---|
| **Contract #:** AV-5590 | **Contract Period:** 5/1/95–12/31/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Florida Solar Energy Center<br>Cocoa, FL 32816-0150- | |
| | **Organization Type**: CU | **Congressional District:** 8 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>S. Durand<br>**Phone:** 407-638-1466 **Fax:** 407-638-1010 | |
| **Technical Monitor:**<br>M. Thomas<br>**Phone:** 505-844-1548<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $380,000<br>1997: $650,000<br>1998: $600,000 | **Cost Share Funding:** |

**Project Objective:** Support US PV Industry and DOE PV Program personnel.

**Approach/Background:** Regional assistance with agencies and utilities, integration of buildings program at FSEC with PO, and education and training for regional customers.

**Status/Accomplishments:** Developed report and videotape on side-by-side comparison of super energy efficient housing with and without PV. Developed utility interconnection workshops integrating IEEE 929 and NEC for Chicago Regional Support Office and Atlanta Regional Support Office, Southeast Region.

**FY 1999 Milestones:** Develop technical assistance to Lakeland UPVG project. Develop hurricane-resistant PV building design for Florida.

**Major Reports Published in FY 1998:**
Monthly Progress Report: "Photovoltaic and Building Projects: Services Offered to Florida Utilities," FSEC.
Monthly Progress Report: "PV Field Monitoring," FSEC.
S. Durand, et al. "Evaluation of the E. Dale Joyner Nature Preserve PV Systems at St. Johns River Power Park, Pelotes Island, Florida."
S. Durand, et al. "Lead Acid Battery Evaluation for Small Stand-Alone Photovoltaic Systems, Interim Working Plan."
S. Durand, et al. "Monitoring the Operation of Photovoltaic Systems on Buildings."
S. Durand, et al. "The Impact of PV on Energy-Efficient Housing."
"Photovoltaic Program at the Florida Solar Energy Center," FSEC.
"A Summary Report on the Application of Photovoltaic Systems and Metal Roofs," FSEC.

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# PV Opportunity Assessment and Projects

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|---|---|
| **Contract #:** AJ-3077 and AU-5830 | **Contract Period:** 10/1/94–9/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | National Park Service<br>Denver, CO 80225-0287 | |
| | **Organization Type**: US | **Congressional District:** 6 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Pat Fleming<br>**Phone:** 303-969-2244 **Fax:** 303-969-2930 | |
| **Technical Monitor:**<br>H. Post<br>**Phone:** 505-844-2154<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>National Park Service |
| | **DOE Funding Allocation:**<br>1995: $180,000<br>1996: $250,000 | **Cost Share Funding:**<br>1995: $180,000<br>1996: $200,000<br>1997: $258,128<br>1998: 0 |

**Project Objective:** In partnership with the National Park Service (NPS) and the DOE, through Sandia National Laboratories, photovoltaic project opportunities are identified and systems are designed and installed.

**Approach/Background:** Opportunities for the Park Service abound, and this contract allows Park Service engineers to conduct their own assessments, as well as install pilot projects to gain experience with PV systems. Hardware for these projects is funded by the NPS and, therefore, the actual cost-share amount varies. However, the minimum amount of cost-sharing is equal to the amount of DOE funds.

**Status/Accomplishments:** Opportunity assessment completed and published. Over 30 projects completed that have installed PV systems at national park sites, especially augmenting or replacing existing diesel generators at small facilities..

**FY 1998 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998**
*Renew the Government: Summary of Projects and Lessons Learned*.

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# Development of Test Methods and Procedures for Evaluation of PV Systems

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|---|---|
| **Contract#:** AAD-7-17628-01 | **Contract Period:** 5/1/97–5/1/98 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | NEOS Corporation<br>165 South Union Blvd.<br>Lakewood, CO 80228 | |
| | **Organization Type:** IN | **Congressional District:** 6 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>T. Schuyler<br>**Phone:** 303-980-1969 **Fax:** 303-980-1030 | |
| **Technical Monitor:**<br>R. DeBlasio<br>**Phone:** 303-384-6452<br>**Fax:** 303-384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1997: $ 48,987 | **Cost Share Funding:** |

**Project Objective:** Identify and develop PV system performance test methods and procedures for use by the PV standards, testing, and certification bodies

**Approach/Background:** Evaluate the current status of test procedures and adopt or develop draft test procedures for verification and use at NREL in support of developing an interim test procedure

**Status/Accomplishments:** NEOS completed and delivered to NREL on June 15, 1998, a final draft procedure and protocol document. This completed the planned work. The draft procedure was further developed by NREL systems engineers, validated, and finalizing as an NREL interim systems test procedure titled, " Interim Test Methods and Procedures for Determining the Performance of Small PV Systems", (NREL/TP-520-25077), which was published in July 1998. Subcontract completed.

**Planned FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:**,
*NREL Photovoltaic Program FY 1997 Annual Report,* NREL/BK-210-23607, (June 1998).
"Interim Test Methods and Procedures for Determining the Performance of Small PV Systems," NREL/TP-520-25077, (July 1998).

**Major Articles Published in FY 1998:**
Second World Solar Conference, Vienna, Austria, "Development of Interim Test Methods and Procedures for Determining the Performance of Small PV Systems," (July 1998).
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press).

## Systems Performance and Engineering

# Reliability Database

| **Contract #:** BC-6226 | **Contract Period:** 4/9/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | PowerLight Corporation<br>Berkeley, CA | |
| | **Organization Type**: IN | **Congressional District:** 9 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>D. Shugar<br>**Phone:** 510-540-0550 **Fax:** 510-540-0552 | |
| **Technical Monitor:**<br>A. Maish<br>**Phone:** 505-844-2154<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $25,000 | **Cost Share Funding:** |

**Project Objective:** Support to examine the reliability aspects of a PowerGuard system installed along with a 100kWp rooftop PV system. Knowledge is necessary to determine whether there are tradeoffs in the long-term reliability of the PowerGuard system under high ambient temperature and ultra-violet radiation regime of roofs.

**Approach/Background:** Contract will identify which specific aspects of the PowerGuard system reliability to address, will prepare reliability analysis data gathering plan, and will perform a reliability analysis.

**Status/Accomplishments:** Prepared reliability analysis and implemented same. Prepared a report on potential failure mechanisms. Installed system quality procedure, which included developing an installation checkout procedure and long-term system monitoring of specific items in the system that were identified as potential failure areas.

**FY 1999 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# PV Certification and Accreditation Management Support

| **Contract#:** AAX-7-16821-01 | **Contract Period:** 11/8/96–11/17/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Power Mark Corporation<br>4044 East Whitton<br>Phoenix, AZ 85018-5940 | |
| | **Organization Type:** IN | **Congressional District:** 1 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>S. Chalmers<br>**Phone:** 602-955-7214 **Fax:** 602-955-7295 | |
| **Technical Monitor:**<br>R. DeBlasio<br>**Phone:** 303-384-6452<br>**Fax:** 303-384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1996: $49,970 1997: $ 35,000 | **Cost Share Funding:** |

**Project Objective:** To support Power Mark Corporation to manage and administer the operation of a component and system certification and laboratory accreditation program. Administer corporate board and committee activities, and liaison activities with domestic and international organizations associated with certification, accreditation, standards, codes, and test method development and validation.

**Approach/Background:** The development of a domestic PV system and component certification and test facility accreditation program that is recognized, has reciprocity between other organizations and has testing conducted by accredited test facilities and products manufactured in a quality environment is a key to a PV component and system quality system. Power Mark Corporation was created to implement and manage a PV module certification program based on the ASU/ NREL/DOE study and has expanded it's role to include systems /components.

**Status/Accomplishments:** The PoweMark Corporation (PMC) board, technical, accreditation, and quality subcommittees have been in operation for over two years. The Board membership was increased from 7 to 10 members in 1998 and includes representatives from ASE Americas, BP Solar, Colorado Office of Energy Conservation, EBARA, Trace Engineering, Siemans Solar, Solarex, and United Solar Systems. Two major module manufactures have modules that have passed the PMC testing and quality certification requirements. Integration with the international PV Global approval Program (PVGAP) is well underway to harmonize the national and international certification activities with IECQ and the National Supervising Inspectorate (NSI), and Underwriters Laboratories (UL). PVGAP has designated SEIA as the licensee and PMC to administer the audit body function for UL/NSI activities in the U.S.

**Planned FY 1999 Milestones:** Hold monthly meetings (Tele-conferences) of the PMC Board. Increase industry representation on the board and committees from component and systems sectors. Exert best efforts to encourage reciprocity protocols from associated certification programs. Maintain a PMC web site and provide presentations of PMC and PVGAP at technical and industry meetings. Facilitate the IECQ approval of U.S. laboratories and manufactures. Establish criteria with NSI/UL for the designated audit functions.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).
Subcontract monthly reports, meeting minutes and annual reports.

**Major Articles Published in FY 1998:**
Promotional material describing the PMC organization and benefits of PMC certification were provided during presentations at the IEEE SCC21 meetings and SOLTECH 1998 meeting.

## Systems Performance and Engineering

# Management and Administration of the IEC TC 82

| **Contract#:** ACU-7-17605-01 | **Contract Period:** 4/26/97–4/25/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Solar Energy Industries Association<br>122 C Street, NW, 4th Floor<br>Washington, DC 20001 | |
| | **Organization Type:** TA | **Congressional District:** AL |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>J. Anderson<br>**Phone:** 828-495-1274 **Fax:** 602-530-4242 | |
| **Technical Monitor:**<br>R. DeBlasio<br>**Phone:** 303-384-6452<br>**Fax:** 303-384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1996: $ 80,262 1997: $ 65,000 | **Cost Share Funding:** |

**Project Objective:** To support an appropriate organization (SEIA) designated by the ANSI USNC (American National Standards Institute, United States National Committee) to manage and administer Secretariat responsibilities for the International Electrotechnical Commission (IEC) PV/Technical Committee (TC) 82 for PV Solar energy systems standards, and coordinate and support U.S. technical participation in the IEC PV/TC82 and its working groups.

**Approach/Background:** The IEC TC-82 is an international standards making committee on solar PV energy systems. The committee prepares consensus international standards and publishes them for the PV industry and community. The committee consists of 5 working groups on glossary, modules, systems, certification, and BOS components plus a sixth group on batteries, which is shared with TC21.

**Status/Accomplishments:** There are 21 participating (voting status) and 12 observing (commentary status) countries involved in TC 82 work. Currently, 24 standards have been published. Work is underway on a PV module safety standard, a PV module power and energy rating standard, a comprehensive Part 2 to the Glossary Technical Report, a system standard for small stand-alone systems, an inverter efficiency standard, an inverter safety standard, a total quality program standard for product certification/laboratory accreditation, and an environmental test standard for the type approval of BOS components.

**Planned FY 1999 Milestones:** To conduct TC82 and working group meetings, and to establish two new working groups: one for PV concentrators and trackers, and another for energy storage system requirements, including, but not limited to battery requirements.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report,* NREL/BK-210-23607, (June 1998).
TC82 committee and working group meeting reports, and subcontract monthly, quarterly and annual reports.

**Major Articles Published in FY 1998:** Published IEC TC82 standards during this reporting period include the following:
1. IEC 60904-2: Edition 1, Amendment 1 (1998), Photovoltaic devices - Part 2: Requirements for reference solar cells
2. IEC 60904-6: Edition 1, Amendment 1 (1998), Photovoltaic devices - Part 6: Requirements for reference solar modules
3. IEC 60904-7: Edition 2 (1998), Photovoltaic devices - Part 7: Computation of spectral mismatch error introduced in the testing of a photovoltaic device
4. IEC 60904-8: Edition 2 (1998), Photovoltaic devices Part 8: Guidance for spectral measurement of spectral response of a photovoltaic (PV) device
5. IEC 60904-10: Edition 1 (1998), Photovoltaic devices - Part 10: Linearity measurement methods
6. IEC 61345: Edition 1 (1998), UV test for photovoltaic (PV) modules
7. IEC 61724: Edition 1 (1998), Photovoltaic system performance monitoring - guidelines for measurement, data exchange and analysis
8. IEC 61836: Edition 1 (1998), Solar photovoltaic energy systems - terms and symbols

## Systems Performance and Engineering

# SWRES Field Evaluation, NEC and Standards Development, Mexico Support

| **Contract #:** AV-5589 | **Contract Period:** 3/19/97–9/30/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Southwest Technology Development Institute<br>Box 30001, Dept. 3SOL<br>Las Cruces, NM 88003-0001 | |
| | **Organization Type**: CU | **Congressional District:** 2 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>A. Rosenthal<br>**Phone**: 505-646-1323 **Fax**: 505-646-3841 | |
| **Technical Monitor:**<br>M. Thomas<br>**Phone:** 505-844-1548<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1994: $263,000<br>1995: $404,000<br>1996: $400,000<br>1997: $780,000<br>1998: $600,000 | **Cost Share Funding:** |

**Project Objective:** Utilize field experience to monitor performance of systems.

**Approach/Background:** Systems installed are monitored for initial performance, performance changes, and safety issues.

**Status/Accomplishments:** Documented performance and economics of PV-hybrid power systems at ASES, IEEE, and in Sandia's Quarterly Report. Provided field data reports from large utility-connected, residential grid-connected, and remote distributed hybrid power systems.

**FY 1999 Milestones:** Document technical assistance to Tucson UPVG project. Conduct six PV/NEC workshops for state electrical inspectors.

**Major Reports Published in FY 1998:**
Rosenthal, A., et al. "Economics and Performance of PV Hybrid Power Systems: Three Case Studies."
Rosenthal, A., et al. "Economic Analysis of PV Hybrid Power System: Pinnacles National Monument."
"Maintaining Large Photovoltaic Power Systems: Concepts and Costs," SWTDI.
"Needles District Canyonlands National Park Photovoltaic System: Site and Electrical System Survey and Test Plan," SWTDI.
"Grid-Connected PV Systems for Residences: A Guide for Project Developers," SWTDI.
"Test Report: Sacramento Municipal Utility District: Photovoltaic Systems at Rancho Seco and the Hedge Sites," SWTDI.

**Major Articles Published in FY 1998:** None.

## Systems Performance and Engineering

# PV Opportunity Assessment and Projects

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| **Contract #:** Al-0809 and AU-5831 | **Contract Period:** 10/1/94–9/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | U.S. Forest Service<br>Phoenix, AZ 85010- | |
| | **Organization Type**: US | **Congressional District:** 2 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Andy Dziobek<br>**Phone:** 602-225-5319 **Fax:** 602-225-5295 | |
| **Technical Monitor:**<br>H. Post<br>**Phone:** 505-844-2154<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**: |
| | **DOE Funding Allocation:**<br>1995: $75,000<br>1996: $100,000<br>1997: $0<br>1998: $0 | **Cost Share Funding:**<br>1995: $75,000<br>1996: $100,000<br>1997: $0<br>1998: $0 |

**Project Objective:** In partnership with the US Department of Agriculture's Forest Service (USFS) and the DOE, through Sandia National Laboratories, photovoltaic project opportunities are identified and systems are designed and installed.

**Approach/Background:** Opportunities for the U.S. Department of Agriculture's Forest Service (USFS) abound, and this contract allows Forest Service engineers to conduct their own assessments, as well as install pilot projects to gain experience with PV systems. Hardware for these projects is funded by the USFS and, therefore, the actual cost-share amount varies. However, the minimum amount of cost-sharing is equal to the amount of DOE funds.

**Status/Accomplishments:** Opportunity assessment completed and published. Over 25 projects completed that have installed PV systems at Forest Service sites, mainly for recreational development at campgrounds.

**FY 1999 Milestones:** None. Contract ended.

**Major Reports Published in FY 1998:** *Renew the Government: Summary of Projects and Lessons Learned.*

**Major Articles Published in FY 1998:** None.

## Building-Integrated Photovoltaics

# PV:BONUS Two - PV String Inverters

| **Agreement#:** DE-FC36-97GO10261 | **Project Period:** 9/30/97–12/31/00 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Advanced Energy Systems, Incorporated (AES)<br>Riverview Mill<br>Wilton, NH 03086 | |
| | **Organization Type:** IN | **Congressional District:** 2 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Dr. Robert H. Wills<br>**Phone:** 603-654-9322 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Advanced Energy Systems, Inc. |
| | **DOE Funding Allocation:**<br>1997: $44,999<br>1998: $90,833 | **Cost Share Funding:**<br>1997: $13,527<br>1998: $90,833 |

**Project Objective:** Advanced Energy Systems, Inc. proposes to design and manufacture a low cost String Inverter System (SIS), which will minimize the cost of the electrical BOS (i.e., the inverter and the PV output circuit wiring). The SIS is an inverter and associated wiring that is designed to operate with a single string of photovoltaic (PV) modules. By using a single string, the need for an expensive string-combiner is eliminated. The parallelling of multiple strings is accomplished by the utility or AC side of the system, lending to inexpensive installation costs.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding of which Advanced energy Systems (AES) was one. The activities to be undertaken in Phase 2 include: 1) product development and testing; 2) market planning; and 3) business development. The key concept is a String Inverter Module or SIM rated at 250 V dc input, at about 4 amps. Its output is 12OV, 8 Amps or 1 kW per module. These power modules use similar construction and packaging to AC module micro-inverters. Up to four SIMs can be mounted in one enclosure which also houses DC source circuit fuses and disconnects, and the AC output circuit breaker. The SIM units are cooled via an integral natural convection "chimney" built into the enclosure - no fans are used and all electronic components are isolated from the environment. In the second part of the project, Advanced Energy Systems will develop low cost wiring and interconnection components for the complete PV system including cables, connectors, disconnect and GFI protection devices. SIM refers to the standardized, modular systems designs coming out of this work as String Inverter Systems (SISs). Advanced Energy Systems has proposed a six (6) month Phase 2 (July 1, 1998 through December 31, 1998) followed by a two (2) year Phase 3 period (January 1, 1999 through December 31, 2000).

**Status/Accomplishments:** During Phase 1, AES designed and constructed a prototype unit which will be simple and inexpensive to manufacture and incorporates the inverter, DC source circuit string combiner, DC ground fault interrupter and disconnect, and an optional AC output circuit breaker, all in one enclosure, named this unit the "GC-1000". The GC-1000 is cooled via an integral natural convection duct built into the back mounting plate - no fans are used and all electronic components are isolated from the environment.

**Planned FY 1999 Milestones:** In Phase 2, AES will continue development of the GC-1000 by taking the prototype unit through UL testing and a manufacturing review, to field and test a number of pre-production units so that reliability and performance can be assured, and to begin marketing and business development activities.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - Ballast-Mounted PV Arrays

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|---|---|
| **Agreement#:** DE-FC36-97GO10257 | **Project Period:** 9/30/97–09/30/00 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Ascension Technology, Incorporated<br>235 Bear Hill Road<br>Waltham, MA 01773 | |
| | **Organization Type:** IN | **Congressional District:** 7 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Edward C. Kern Jr.<br>**Phone:** 617-684-6101 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Ascension Technology, Incorporated |
| | **DOE Funding Allocation:**<br>1997: $44,160<br>1998: $43,328 | **Cost Share Funding:**<br>1997: $11,200<br>1998: $43,500 |

**Project Objective:** Ascension Technology for the development of analytic and experimental capabilities for quantifying the balance between driving (wind, seismic) forces and the restraining (gravitational/frictional) forces that must exist for the ballast-mounting approach to succeed. Ascension Technology and its partners to address wind loading on solar panels and the suitability of using frictional forces between ballast trays and roofing materials to resist wind on the PV arrays. The primary goal of the project is to capture the potential cost savings made possible by ballast-mounting by showing under what conditions it can satisfy wind loading concerns with a secondary goal is to address the more geographically constrained concern regarding withstanding seismic forces.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding of which Ascension was one. The activities to be undertaken in Phase 2 include: 1) product development and testing; 2) market planning; and 3) business development. Ascension Technology and its partners to address wind loading on solar panels and the suitability of using frictional forces between ballast trays and roofing materials to resist wind on the PV arrays. Ascension Technology to will validate analytic methods for predicting wind speed thresholds for ballasted PV arrays sliding across roofs and develop means to improve the frictional resistance of ballast mounting techniques. Additionally, under Phase 2, Ascension Technology will develop and test new array attachment concepts as successors to our present ballast tray and flat Roof-Jack products.

**Status/Accomplishments:** In Phase 1 of this project, Ascension Technology developed the analytic and experimental capabilities for quantifying the balance between driving (wind, seismic) forces and the restraining (gravitational/frictional) forces that must exist for the ballast-mounting approach to succeed.

**Planned FY 1999 Milestones:** Phase 2 of the project is a twelve (12) month test and evaluation period with the goal of proving a correlation between measured and analytically predicted wind loading and sliding friction resistance of the ballast-mounted PV array system. During Phase 2, Ascension Technology will conduct tests on wind forces on PV arrays at two locations, including coastal (i.e., Newburyport, MA) and mountain (i.e., National Wind Technology Center at Rocky Flats, CO) locations susceptible to high wind load. Ascension Technology will conduct tests on the sliding friction resistance of ballast-mounted trays with EPDM, modified bitumen, and hyphalon/CE single ply roofing membrane types at each location. Following testing, the measured and analytically predicted wind loading and sliding friction resistance will be compared and the accuracy of the methods reported.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - Rooftop Integrated Photovoltaic System

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| **Agreement#:** DE-FC36-97GO10246 | **Project Period:** 9/30/97–06/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | AstroPower, Incorporated<br>Solar Park<br>Newark, DE 19716 | |
| | **Organization Type:** IN | **Congressional District:** AL |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Louis C. DiNetta<br>**Phone:** 302-366-0400 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>AstroPower, Incorporated |
| | **DOE Funding Allocation:**<br>1997: $49,947<br>1998: None | **Cost Share Funding:**<br>1997: $13,302<br>1998: None |

**Project Objective:** The primary objective of this PV:BONUS Two project is for AstroPower, in conjunction with Solar Design Associates and Royal Group Technologies, to develop an integrated photovoltaic roofing system for residential and light commercial building applications. The family of products will rely heavily on the technological development of a recycled plastic roofing tile and innovative module fabrication and encapsulation process in conjunction with AstroPower's advanced Silicon-Film™ Product III. The proposed product is presently being referred to as the SolarTile. The SolarTile will be integrated with non-solar tiles in a single roof installation permitting ease of assembly and the ability to use conventional roofing techniques at ridges, valleys, and eaves. Compatibility with standard structure will be insured by designing panels that are readily installed to replace and function as roofing with conventional fastening methods.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. AstroPower was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the Solar Tile concept was developed. AstroPower completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS One - Dispatchable PV Peak Shaving System

| **Agreement#:** DE-FC36-93CH10569 | **Project Period:** 06/01/93–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Delmarva Power and Light Company<br>P.O. Box 231<br>Wilmington, DE 19899-0231 | |
| | **Organization Type:** IN | **Congressional District:** 01 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>William Ferguson<br>**Phone:** 302-429-3055 **Fax:** 302-429-3801 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Delmarva Power and Light Company |
| | **DOE Funding Allocation:**<br>1993: $275,000 1996: $76,000<br>1994: $284,717 1997: $38,307<br>1995: $355,900 1998: None | **Cost Share Funding:**<br>1993: $206,542 1996: $168,509<br>1994: $213,040 1997: $169,310<br>1995: $177,715 1998: $112,339 |

**Project Objective:** The objective of the project is for the development and demonstration of a Dispatchable Photovoltaic Peak Shaving System for commercial application. the product concept goal was to develop a dispatchable photovoltaic system for commercial application utilizing modular construction and a simple-roof mounting, flexible design in compliance with building and safety codes.

**Approach/Background:** In July 1993, Delmarva Power was awarded an agreement to develop a PV peak shaving system based on work performed by the University of Delaware Center for Energy and Environmental Policy (CEEP) in 1992. Under Phase 1 of the PV:BONUS program, resulted in the achievement of the goals that produced a modular, grid-connected dispatchable PV system. Achievements included: 1) successful deployment and testing of a demonstration system; 2) refinement of the controls, electrical integration, and mechanical packaging of the battery/inverter module; 3) refinement of the PV array integration and packaging approach; 4) development of a roof mounting system for commercial structures; and 5) development of system sizing methodology. Phase I also included market analysis and commercialization activities which resulted in identifying significant markets for both on-grid and off-grid modules of the system, developing an understanding of system economics, and developing the organizational relationships for system commercialization. Phase 2 of the PV:BONUS Program will build on the results of Phase 1 to refine and commercialize the Dispatchable Peak Shaving System. The overall objectives of Phase 2 include: 1) install and measure performance of four Dispatchable PV Peak Shaving units to validate both the designs; 2) develop and deploy an off-grid unit; 3) identify technical improvements and cost reductions necessary for commercial introduction; 4) identify and analyze economic and policy strategies which facilitate the commercial introduction of the system; 5) fully develop the strategic alliances, manufacturing and support infrastructure necessary for production, installation and servicing; and 6) acquire the market knowledge and develop the marketing plans necessary to focus on "early adopters."

**Status/Accomplishments:** The four grid-connected systems have been installed. Sites for the four systems include: 1) Delmarva's Conowingo District Office in Maryland; 2) Carvel State Office Building in Wilmington, Delaware; 3) Wisconsin Public Service/Shopko Building in Greenbay, Wisconsin; and 4) INTEK Corporation's textile manufacturing plant in Aberdeen, North Carolina. Development of the grid-independent PV/UPS system continued with a prototype completion in 1997. Installation of the PV/UPS system in Dover, Delaware, at a State of Delaware Division of Facilities Management site was completed in August 1998. Additionally, monitoring and data analysis continued and the market analysis for both the grid-connected and the grid-independent systems was completed.

**Planned FY 1999 Milestones:** Completion of the final report is planned by December 31, 1998.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

# PV:BONUS Two - Photovoltaic AC "Mini-Grid" System

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| **Agreement#:** DE-FC36-97GO10254 | **Project Period:** 9/30/97–06/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Delmarva Power & Light Company<br>800 King Street<br>Wilmington, DE 19899 | |
| | **Organization Type:** IN | **Congressional District:** AL |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>William Ferguson<br>**Phone:** 302-429-3055 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Delmarva Power & Light Company |
| | **DOE Funding Allocation:**<br>1997: $50,000<br>1998: None | **Cost Share Funding:**<br>1997: $103,703<br>1998: None |

**Project Objective:** Delmarva Power & Light Company and its partners, Applied Energy Group, AC Battery Corporation, Advanced Energy Systems, Ascension Technology, Solarex, and the University of Delaware, propose to develop a photovoltaic AC "Mini-Grid" system for use on commercial buildings. Simple, grid-interactive PV systems cannot compete economically with grid-supplied electricity in the United States. Conventional grid-interactive PV systems also require field installation of DC wiring and DC-rated balance-of-system electrical equipment. Engineers, architects and installers are often unfamiliar with proper DC electrical design and installation practices, and DC-rated equipment is often difficult to find and expensive. The value of the AC Mini-Grid system will be considerably higher than conventional grid-interactive PV systems because it will be capable of providing power conditioning, peak shaving, uninterruptible power supply (UPS), and stand-alone operating functions.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. Delmarva Power & Light Company was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the photovoltaic AC "Mini-Grid" system concept was developed. Delmarva Power & Light Company completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS One - Rooftop Photovoltaic Systems

| **Agreement#:** DE-FC36-93CH10571 | **Project Period:** 06/01/93–05/01/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Energy Conversion Devices (ECD)<br>1675 West Maple Road<br>Troy, MI 48084 | |
| | **Organization Type:** IN | **Congressional District:** 12 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Masatsugu Izu<br>**Phone:** 810-280-1900 **Fax:** 810-280-1456 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Energy Conversion Devices (ECD) |
| | **DOE Funding Allocation:**<br>1993: $200,000 1996: $1,077,176<br>1994: $625,000 1997: $333,374<br>1995: $1,953,736 1998: None | **Cost Share Funding:**<br>1993: $605,545 1996: $1,171,098<br>1994: $605,315 1997: $362,442<br>1995: $1,967,635 1998: None |

**Project Objective:** The overall objective of the project is to develop a rooftop photovoltaic system using modules that can replace conventional roofing materials and that can be economically and aesthetically be integrated into residential and commercial buildings. The overall objective of the project is to develop a rooftop photovoltaic system using modules that can replace conventional roofing materials and that can be economically and aesthetically be integrated into residential and commercial buildings.

**Approach/Background:** The project is currently starting the third phase of a three phased program to develop and demonstrate the both shingle type and large laminate rooftop modules. Phase 2 consisted of prototype manufacturing, development of detailed system design and installation method, testing and qualification for the two module types, demonstration building design, market assessment, and business development. The metal roofing system, developed by ECD, is mechanically identical to a commercially-available metal roofing system and the prototype shingle PV roofing system arrays, developed by UniSolar, emulate and replace standard asphalt shingles. During Phase 3, ECD has proposed to deploy and test three field demonstrations. Two of the demonstration sites, a historic island guest house under restoration for use as a Bed and Breakfast and the "Energy Smart" townhouse at NAHB Research Center, are planned for the metal roofing system. The PV shingle-type roof system is planned to be installed on a house to be built in Atlanta, Georgia, prior to the 1996 Olympics. The Atlanta house, intended to showcase state-of-the-art renewable energy and energy-efficient technologies, will be located next to the Science and Technology Museum and incorporate a grid-connected 1.9 kW system. Additionally, the house annex, or garage area, will be designed as a demonstration site for visitors to view the photovoltaic module interconnects, as would be in the attic of a house using PV shingles. ECD's metal roofing array was installed on the NAHB Research Center 21 st Century Townhouse in Bowie, Maryland in May 1996. The PV shingle-type roof system was installed on Southface Energy Efficiency House in the Olympic Village in Atlanta, GA in June 1996. The shingle PV module has received awards from Popular Science (The Best of What's New Grand Award) and Discovery magazines. The UL approved Building-integrated Photovoltaic (BIPV) modules have been introduced into United Solar's 5 MW production line with the shingle modules currently being produced at a rate of 40 kW per month. ECD/USSC offer five (5) standard commercial products: the shingle module and a family of standing seam metal roofing laminates that can be integrated with either architectural or structural metal pans.

**Status/Accomplishments:** The UL approved Building-integrated Photovoltaic (BIPV) modules are currently available commercially through United Solar systems Corporation

**Planned FY 1999 Milestones:** Continue to offer the shingle and standing metal PV module systems commercially. Complete and submit the project final report.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - PV/Thermal Solar Metal Roofing System

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| **Agreement#:** DE-FC36-97GO10252 | Project Period: **9/30/97–06/30/98** |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Energy Conversion Devices, Incorporated<br>1675 West Maple Road<br>Troy, MI 48084 | |
| | **Organization Type:** IN | **Congressional District:** 12 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Nancy Bacon<br>**Phone:** 248-280-1900 **Fax:** 248-280-1456 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Energy Conversion Devices, Incorporated |
| | **DOE Funding Allocation:**<br>1997: $50,000<br>1998: None | **Cost Share Funding:**<br>1997: $123,156<br>1998: None |

**Project Objective:** Energy Conversion Devices, Inc. (ECD), in association with United Solar, the NAHB Research Center, Florida House Institute, Sustainable Energy Systems, Thermal Conversion Technology, and two metal roofing companies (ATAS International and McElroy Metals) to develop two new metal roofing panels that will be designed to be exact replacements for standard roofing panels: (1) a hot-water metal roofing panel, and (2) a hot-air metal roofing panel.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. Energy Conversion Devices was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the PV/Thermal Solar Metal Roofing concept was developed. ECD completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - SunFlash: PV Module with Integral Flashing

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|---|---|
| **Agreement#:** DE-FC36-97GO10248 | **Project Period:** 9/30/97–6/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Evergreen Solar, Incorporated<br>211 Second Avenue<br>Waltham, MA 02178 | |
| | **Organization Type:** IN | **Congressional District:** 8 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Jack I. Hanoka<br>**Phone:** 617-890-7117 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Evergreen Solar, Incorporated |
| | **DOE Funding Allocation:**<br>1997: $50,000<br>1998: None | **Cost Share Funding:**<br>1997: $48,000<br>1998: None |

**Project Objective:** This grant includes those activities to be undertaken by Evergreen Solar and its partners, Ascension Technology, Jefferson Shingleton, P.E., and Bechtel, for the development of the SunFlash, an innovative and unique new building product. The SunFlash is unique because it is the first photovoltaic (PV) module with an integral flashing. This integral flashing will enable simple and cost effective applications that require watertight sealing in a variety of different mountings. This advancement is only possible because of Evergreen's development of an advanced and proprietary backskin material.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. Evergreen Solar was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the SunFlash concept was developed. Evergreen Solar completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS One - Integrated Modular Homes

| **Agreement#:** DE-FC36-93CH10568 | **Project Period:** 08/01/93–12/31/98 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>R. Hassett — **Phone:** 202-586-8163 — **Fax:** 202-586-8148 | Fully Independent Residential Solar Technology (FIRST)<br>66 Syndertown Road<br>Hopewell, NJ 08525 | |
| | **Organization Type:** IN | **Congressional District:** 12 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Lyle Rawlings<br>**Phone:** 609-466-4495 **Fax:** 609-466-3631 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Fully Independent Residential Solar Technology (FIRST) |
| | **DOE Funding Allocation:**<br>1993: $100,000 — 1996: $177,265<br>1994: $193,589 — 1997: $24,660<br>1995: $275,265 — 1998: None | **Cost Share Funding:**<br>1993: $153,887 — 1996: $164,124<br>1994: $237,000 — 1997: $125,683<br>1995: $295,964 — 1998: $75,000 |

**Project Objective:** The prime objective of the project is to design, develop, and introduce to the residential market a line of integrated, modular solar homes designed for photovoltaic power. The intent of the project is to optimize home designs for least-cost construction, high performance, reliability, and to put in place the necessary marketing and distribution networks, financial products, and utility sector encouragement to ensure product success.

**Approach/Background:** The product concept is a factory-manufactured home which is designed from the ground-up to integrate PV power, high-efficiency appliances and light, passive solar heating and cooling architecture, and offers solar hot water as an option. The home, including the solar systems, wiring and controls, key appliances, and lights, will be produced by a major manufactured housing company which specializes in modular homes.

**Status/Accomplishments:** Phase 1 (6/1/93-6/1/94) included design and initiation of pilot home construction. Phase 2 included final design and completion of six pilot homes. Phase 3 planned activities include: the implementation of PV-integrated modular homes into sustainable communities and low-income housing projects; establishment of partnerships with the EPA Energy Star Home Program for "Energy Star Mortgages"; investigation of PV/wind hybrid systems; development of a 48 V direct-current ballast for compact fluorescent lamps; and development of large, lightweight, roof-integrated modules. Nine townhomes in a Philadelphia low-income housing project, seven homes for the New Alchemy Farms Sustainable Community (Cape Cod, MA) and completion of the Long Island home are planned during Phase 3. FIRST installed a factory-built home featuring photovoltaic hardware and passive solar/energy efficient design features in the Washington area during the Solar energy Forum held April 1997. A low-income home was completed in Jersey City in conjunction with a minority housing development and training corporation who may utilize the PV-integrated home concept in future developments. Three integrated, modular solar homes have been completed as part of the New Alchemy Farms Sustainable Community with eighteen planned for the Philadelphia low-income housing project. The three new Alchemy homes resulted in substantial lower costs ($20 per foot less) than conventional homes in the community. Large-area module development has been completed with prototypes planned for November 1997. Solarex is considering including the roof-integratable large-area module into their product line. The pre-framed large-area modules incorporate numerous cost reduction advancements by using a plastic framing assembly which allows interlocking of the modules, reduces weight, provides water-tight seals, simplifies plug wiring, negates grounding requirements, and reduces the installation time.

**Planned FY 1999 Milestones:** Complete the construction of the 18 PV integrated modular homes as part of Philadelphia's low-income housing project.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - Flexible, Laminated Copper-Indium-Gallium-Diselenide for Building Materials

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| **Agreement#:** DE-FC36-97GO10256 | **Project Period:** 9/30/97–06/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Global Solar Energy, LLC<br>12401 West 49th Avenue<br>Wheat Ridge, CO 80033 | |
| | **Organization Type:** IN | **Congressional District:** 2 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Dr. Joseph H. Armstrong<br>**Phone:** 303-420-1141 **Fax** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Global Solar Energy, LLC |
| | **DOE Funding Allocation:**<br>1997: $54,149<br>1998: None | **Cost Share Funding:**<br>1997: $31,176<br>1998: None |

**Project Objective:** Global Solar Energy (GSE) is proposing the development of flexible CIGS laminated onto building materials. Direct lamination of this material onto building materials will result in several possible product configurations, each will provide power generation where presently none exists at the power output capacity of CIGS. Such configurations can accommodate both industrial commercial and residential structures, with installation conforming to standard industry preparation and installation practices.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. Global Solar Energy was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the flexible, laminated copper-indium-gallium-diselenide for building materials concept was developed. Global Solar Energy completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS One - Architectural PV Glazing System

| **Agreement#:** DE-FC36-95GO10013 | **Project Period:** 01/10/95–04/30/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Innovative Design, Incorporated<br>850 West morgan Street<br>Raleigh, NC 27603 | |
| | **Organization Type:** IN | **Congressional District:** 04 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Michael Nicklas<br>**Phone:** 919-832-6303 **Fax:** 919-832-3339 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Innovative Design, Incorporated |
| | **DOE Funding Allocation:**<br>1995: $225,000 1996: $30,175<br>1997: $74,609 1998: None | **Cost Share Funding:**<br>1995: $88,288 1996: $181,540<br>1997: $40,368 1998: $23,548 |

**Project Objective:** The principle objective of this revised, single-phase PV:BONUS project is to design and construct two roof-integrated photovoltaic systems that will serve to facilitate the development of two specific photovoltaic product lines, establish partnerships with the building product industry in order to manufacture product prototypes, solicit a partnership from the public sector in order to demonstrate the product in viable commercial sector applications, and to test and monitor the two applications.

**Approach/Background:** DOE originally entered into an agreement with Advanced Photovoltaic Systems, Inc. (APS) for work under the PV:BONUS Program. This work is now being performed by Innovative Design (ID) under the mutual agreement of APS and DOE. The two systems for development by Innovative Design are: 1) Applebee's Restaurant; and 2) Central Carolina Bank. The Applebee's PV application will substitute for the roof assembly of a low-sloping sunspace roof that is typically made of clay tile. The 1 to 2 kW peak system will also feature a heat recovery aspect. The design will allow for the entire roof assembly to be pre-constructed off-site, tested, and then shipped to the site in several large components where it can be erected in a fashion which would drastically reduce the typical time required to install a normally used roof construction. The Central Carolina Bank (CCB) application will substitute for the roof assembly of the drive-in window area of the bank. The design will feature a space truss design which incorporated the photovoltaic array on one side of the truss and a combination of reflective and daylighting panels on the opposite side. Like the Applebee's solution, the design will allow the entire roof assembly to be constructed off-site, tested, and then shipped to the site in pre-assembled large components.

**Status/Accomplishments:** Construction of the Applebee's Restaurant application was completed Fall 1997 with long-term monitoring initiated February 1998. The installation of the Central Carolina Bank system was installed and monitoring initiated January 1998.

**Planned FY 1999 Milestones:** Complete monitoring of both PV/thermal systems planned for February 1999 followed by a final report.

**Major Reports Published in FY 1998: none**

**Major Articles Published in FY 1998:** The installation of the Central Carolina Bank system was installed and monitoring initiated January 1998. The Applebee's PV system with thermal heat recovery system was featured in the May issue of CADDET and featured in the January/February issue of Solar Today.

# PV:BONUS Two - Transparent Building-Integrated PV Modules

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| **Agreement#:** DE-FC36-97GO10261 | **Project Period**: 9/30/97–06/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Kiss + Cathcart, Architects<br>150 Nassau Street<br>New York, NY 10038-1516 | |
| | **Organization Type:** IN | **Congressional District:** 8 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Gregory Kiss<br>**Phone:** 212-513-1711 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Kiss + Cathcart, Architects |
| | **DOE Funding Allocation:**<br>1997: $50,000<br>1998: None | **Cost Share Funding:**<br>1997: $38,599<br>1998: None |

**Project Objective:** Kiss+Cathcart, Architects, in conjunction with Energy Photovoltaics, Incorporated (EPV), propose to develop a flexible patterning system for thin film photovoltaic modules for building applications. The proposers are currently developing a complementary process for the large-scale lamination of thin film PVs, which enables Building-integrated (BIPV) modules to be produced in sizes up to 48" x 96". Flexible laser patterning will be used for three main purposes, all intended to broaden the appeal of the product to the building sector: 1) To create semitransparent thin-film modules for skylights, and in some applications, for vision glazing; 2) To create patterns for decorative effects. This is similar to fritted glass, which is used for shading, visual screening, graphics, and other purposes; and 3) To allow BIPV modules to be fabricated in various sizes and shapes with maximum control over electrical characteristics.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. Kiss+Cathcart, Architects was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the two basic methods for creating transparency via patterning were analyzed. Kiss+Cathcart, Architects completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

# PV:BONUS Two - Fully Integrated, Modular Photovoltaic Uninterruptible Power Supply (PVUPS)

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| **Agreement#:** DE-FC36-97GO10258 | **Project Period:** 9/30/97–06/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Omnion Power Engineering Corporation<br>2010 Energy Drive<br>East Troy, WI 53120 | |
| | **Organization Type:** IN | **Congressional District:** 1 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Hans Meyer<br>**Phone:** 414-642-7200 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Omnion Power Engineering Corporation |
| | **DOE Funding Allocation:**<br>1997: $49,682<br>1998: None | **Cost Share Funding:**<br>1997: $17,456<br>1998: None |

**Project Objective:** Omnion Power Engineering Corporation proposes the development of a fully integrated, modular photovoltaic uninterruptible power supply. The PVUPS™ is intended for use in commercial and industrial facilities housing high value data processing or manufacturing operations. In its normal mode it delivers photovoltaic power to the customer's service. During utility disturbances or outages, the system disconnects the customer's load from the utility and supplies it directly. When the utility service returns, the PVUPS reconnects the utility. All transitions are seamless to avoid disruption of critical loads. Photovoltaic array provides all the benefits of clean, one-site energy generation while significantly extending the system run-time when in the UPS mode.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. Omnion Power Engineering Corporation was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the fully integrated, modular photovoltaic uninterruptible power supply concept was developed. Omnion Power Engineering Corporation completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - PowerRoof 2000

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| **Agreement#:** DE-FC36-97GO10247 | **Project Period:** 9/30/97–09/30/02 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | PowerLight Corporation<br>2954 San Pablo Avenue<br>Berkeley, CA 94710 | |
| | **Organization Type:** IN | **Congressional District:** 9 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Thomas L. Dinwoodie<br>**Phone:** 510-540-0550 **Fax:** 510-540-0552 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>PowerLight Corporation |
| | **DOE Funding Allocation:**<br>1997: $60,844<br>1998: $57,162 | **Cost Share Funding:**<br>1997: $67,000<br>1998: $101,041 |

**Project Objective:** PowerLight Corporation, in cooperation with AstroPower; Solarex; BP Solar; and Siemens Solar, propose to development of an innovative Building-integrated PV roofing system called PowerRoof ™. PowerGuard® is the first core product in the PowerRoof family and has been successfully developed under prior programs. The PowerRoof ™ 2000 proposal targets development of two next-generation core PowerRoof building products, HeatGuard ™ and PowerTherm ™. Each builds upon the proven technological approach of the PowerGuard solar electric roofing system.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding of which PowerLight was one. The activities to be undertaken in Phase 2 include: 1) product development and testing; 2) market planning; and 3) business development. The HeatGuard PV roofing assembly is a patent-pending core product in the PowerRoof line. In addition to generating clean solar electricity, Building-integrated HeatGuard PV systems provide roof protection from solar thermal loads in the cooling season and block radiant building losses in the heating season. This yields significant reductions in building HVAC loads - leading to reductions in energy consumption, energy costs, and system equipment sizing. The PowerTherm PV roofing system pursues existing PowerLight patent claims for hybrid PV/thermal. PowerTherm is a Building-integrated PV/thermal hybrid system designed to couple the benefits of PV power with the collection of thermal energy. The parallel development of HeatGuard and PowerTherm as extensions of the PowerGuard approach is essential, as detail refinement of both projects will yield mutually beneficial technological advancements.

**Status/Accomplishments:** Under Phase 1, PowerLight accomplished the following: 1) received, prototyped, and tested leading advanced thin film materials into PowerRoof assemblies from seven leading manufacturers; 2) optimized and validated HeatGuard to improve the contribution to the building thermal envelop by reducing the rooftop solar absorptance to zero; 3) developed the PowerTherm concept prototype; 4) identified hybrid products using the HeatGaurd and PowerTherm systems.

**Planned FY 1999 Milestones:** Under Phase 2, PowerLight plans to complete the following: 1) finalize selection of the advanced thin film module for integration into the PowerGaurd system and demonstration of a 25 kW HeatGaurd system and a 1 kW PowerTherm array; 2) prototype design, fabrication, and testing of both HeatGaurd and PowerTherm; 3) design and fabricate 25 kW scaleable systems for demonstration; 4) obtain UL approval of both products; 5) and examine a hybrid desiccant dehumidification integrated with a PV/T system.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - Photovoltaic Powered Electrochromic Windows

| **Agreement#:** DE-FC36-97GO10251 | **Project Period:** 9/30/97–09/30/02 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Sage Electrochromics, Incorporated<br>501 Hoes Lane, Suite 208<br>Piscataway, NJ 08854-0278 | |
| | **Organization Type:** IN | **Congressional District:** 6 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>John Van Dine<br>**Phone:** 908-699-1100 **Fax:** 908-699-1101 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Sage Electrochromics, Incorporated |
| | **DOE Funding Allocation:**<br>1997: $60,000<br>1998: $200,331 | **Cost Share Funding:**<br>1997: $42,918<br>1998: $230,409 |

**Project Objective:** Sage Electrochromics, in conjunction with Solarex, propose to develop and commercialize photovoltaic (PV) powered electrochromic (EC) "smart windows" EC windows control the amount of sunlight and solar heat by dynamically switching between darkened and clear states and anywhere in-between. They provide a unique opportunity to realize significant energy savings and reduce peak electrical demand in buildings. The low-power DC voltage required to power the EC window glazing can be supplied by PV solar cells incorporated in the double pane insulating glass unit (IGU) so that no external hard-wired connections are needed.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding of which SAGE was one. The activities to be undertaken in Phase 2 include: 1) product development and testing; 2) market planning; and 3) business development. The project is segmented into three phases over 60 months. In Phase 1, Sage proved the viability of the PV-EC concept and fabricated several 0.1 $m^2$ windows demonstrating operational performance, including wireless control, over a range of solar conditions. In Phase 2, Sage plans to achieve the capability to fabricate limited numbers of full-sized demonstration PV-EC prototype windows which will be used for field demonstration and performance verification. The participant group expanded to include Glass Technologies, world leader in large-area sputtering technology and high performance architectural window fabrication, and Libbey-Owens-Ford, leading producer of conductive glass substrates. During Phase 3, the development of equipment, processes, partnerships, and distribution channels to initiate commercial production and introduction of the PV-EC window product for sale into targeted building markets will be finalized.

**Status/Accomplishments:** In Phase 1, Sage proved the viability of the PV-EC concept and fabricated several 0.1 $m^2$ windows demonstrating operational performance, including wireless control, over a range of solar conditions. The results support a marketing strategy that targets skylights and overhead glazings as first applications. Phase 1 defined the capabilities of this product which led to defining a large size PV-EC windows product that can be used for a variety of architectural window applications.

**Planned FY 1999 Milestones:** Under Phase 2, SAGE a limited number of large size PV-EC windows will be fabricated and tested and accelerated testing will be carried out to assess product durability, and windows will be installed in OEM and end user beta sites to evaluate performance in real application environments. Under Phase 2 the PV-EC demonstration line will be scaled up to medium volume production for commercial sales.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS One - AC PV Module and Curtain Wall Application

| **Agreement#:** DE-FC36-93CH10572 | **Project Period:** 06/01/93–06/03/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Solar Design Associates (SDA)<br>P.O. Box 242<br>Harvard, MA 01451-0242 | |
| | **Organization Type:** IN | **Congressional District:** 05 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Steven Strong<br>**Phone:** 508-456-6855 **Fax:** 508-456-303 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Solar Design Associates (SDA) |
| | **DOE Funding Allocation:**<br>1993: $200,000 1996: $1,077,176<br>1994: $625,000 1997: $333,374<br>1995: $1953,736 1998: None | **Cost Share Funding:**<br>1993: $605,545 1996: $1,171,098<br>1994: $605,315 1997: $362,442<br>1995: $1,967,635 1998: None |

**Project Objective:** The objective of the project is to develop and commercialize a large-area photovoltaic (PV) module with a dedicated, integrally-mounted, DC to AC power inverter, with an electrical output of 60 Hz AC power for compatibility with the utility grid. In addition, an integrated PV curtain wall product specifically for commercial building facades will be developed for commercialization. The AC photovoltaic module will nominally be 4 x 6 feet (24 square feet) in size and designed for direct building integration into the vertical facades and sloped-roof construction of residential, commercial or institutional buildings, replacing the traditional building skin.

**Approach/Background:** Under Phase 1 and 2 of PV:BONUS, a large-area PV module with a dedicated, integrally-mounted, DC to AC power inverter, whose electrical output is 60 Hz AC power which is fully compatible with the utility grid was developed. The module's output is connected directly to the building's AC distribution system without need for any DC wiring, string combiners, DC ground-fault protection or additional power conditioning equipment. The AC module is nominally 4 x 6 feet (24 square feet) in size and designed for direct building integration into the vertical facades and sloped-roof construction of residential, commercial and institutional buildings, replacing the traditional building skin. A framed version of the AC module has also been developed for systems employing tracker and rack mounting.

**Status/Accomplishments:** In Phase 1, Solar Design developed a prototype of the AC module inverter, while Mobil Solar Energy Corporation worked on developing a nominal 50-Volt, 240-Watt, 24 square foot photovoltaic module. During the Phase I effort, Mobil Solar was closed by Mobil Oil and Solarex Corporation, the largest US manufacturer of photovoltaics and the second-largest in the world, agreed to continue the development work in lieu of Mobil Solar. During Phase 2, the Kawneer Company, a leading manufacturer of architectural curtain wall systems, also Joined the SDA team along with the Maryland Energy Administration and Baltimore Gas and Electric. In addition to designing and manufacturing a new large-area PV module to accept the SDA modular inverter, the Solarex / SDA team also developed an integrated PV curtain wall system specifically for commercial building facades and sloped-roof glazing applications. One of the first applications of this new technology was the new entry canopy designed by SDA, for the natatorium complex at the Summer Olympic Games in Atlanta. Here, 18 large-area Solarex AC modules with clear backskins are mounted in a custom, arched support structure by Kawneer, to form the skin of the canopy. The AC Module has received UL approval and is being marketed through Solarex and Kawneer. High-visibility, high-leverage early demonstrations are presently under way at the Olympic village and at the Sacramento Municipal Utility District (SMUD) where the first two roof-top residential AC modules systems of 4 kWp each were fielded. Integration of a large-area thin-film array is planned for the south face of the 12-story high cube at the new Discovery Center, a non-profit science center, is underway with completion planned Fall 1998.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** BIPV presentation at the 2nd world Conference on Photovoltaics in Vienna. Presentations at the American Solar Energy Society conference, American Institute of Architects national convention, SolTech conference; presentations at schools of architecture; and presentations at seven (7) architect BIPV workshops.

## Building-Integrated Photovoltaics

# PV:BONUS Two - Hybrid Photovoltaic/Thermal Collector

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| **Agreement#:** DE-FC36-97GO10250 | **Project Period:** 9/30/97–12/31/01 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Solar Design Associates, Incorporated (SDA)<br>252 Old Littleton Road<br>Harvard, MA 01451-0242 | |
| | **Organization Type:** IN | **Congressional District:** 5 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Steven J. Strong<br>**Phone:** 508-456-6855 **Fax:** 508-456-3030 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Solar Design Associates, Incorporated (SDA) |
| | **DOE Funding Allocation:**<br>1997: $49,969<br>1998: $185,148 | **Cost Share Funding:**<br>1997: $82,762<br>1998: $450,770 |

**Project Objective:** Solar Design Associates, Inc. (SDA), United Solar Systems Corporation (USSC), and SunEarth, Inc., propose to design, develop, demonstrate, manufacture and commercialize a Hybrid Flat-plate Photovoltaic/Thermal (PV/T) Collector to deliver both electricity and thermal energy. The PV/T collector design will employ liquid thermal transfer medium and closely resemble conventional flat-plat solar thermal collectors in size, appearance, installation and function. However, in place of the normal thermal absorber plate, it will employ a PV element of triple-junction amorphous silicon alloy solar cells made with United Solar's proprietary UNISOLAR ™ technology whose material and thermal characteristics are uniquely well suited for combined PV/T applications.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding of which Solar Design Associates was one. The activities to be undertaken in Phase 2 include: 1) product development and testing; 2) market planning; and 3) business development. During Phase 2, Solar Design Associates (SDA), in conjunction with United solar systems Corporation (USSC), and Sun Earth, Incorporated, propose to design and develop a Hybrid Flat-Plate Photovoltaic / thermal (PV/T) Collector to deliver both electricity and thermal energy. The hybrid collector will be fabricated, demonstrated, and verified during Phase 3.

**Status/Accomplishments:** During Phase 1, SDA, in conjunction with United Solar Systems Corporation (USSC) and SunEarth, Inc., developed the conceptual design for the PV/T collector product and fabricated a full-scale conceptual PV/T collector based upon the standard SunEarth thermal collector.

**Planned FY 1999 Milestones:** Based on the product conceptual design and market assessment developed in Phase 1, the Team will perform the detailed product design for the PV/T product, begin fabrication and testing of a scaleable system-level design. Additionally, a production plan for demonstration, market entry and full production of the new hybrid PV/T collector at the SunEarth production facility in California will be initiated.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - Solarex Thin Film Photovoltaics

| **Agreement#:** DE-FC36-97GO10245 | **Project Period:** 9/30/97–06/30/02 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
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| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Solarex<br>630 Solarex Court<br>Frederick, MD 21703 | |
| | **Organization Type:** IN | **Congressional District:** 6 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>John H. Wohlgemuth<br>**Phone:** 301-638-4375 **Fax:** 301-698-4201 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Solarex |
| | **DOE Funding Allocation:**<br>1997: $57,368<br>1998: $164,436 | **Cost Share Funding:**<br>1997: $43,680<br>1998: $165,518 |

**Project Objective:** With the support of subcontractors Kawneer, Solar Design Associates (SDA) and Velux, Solarex will develop building-integrated photovoltaic products using tandem-junction amorphous silicon modules. Major objectives of the program include: 1) developing a commercial photovoltaic curtain wall module (Spandrel Module); 2) developing a commercial photovoltaic sunshade for curtain walls (PowerTint Window); and 3) developing an opaque PV sunshade (PowerShade).

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding of which Solarex was one. The activities to be undertaken in Phase 2 include: 1) product development and testing; 2) market planning; and 3) business development.

Under PV:BONUS One, the team of Solarex, Kawneer and Solar Design Associates (SDA) developed a crystalline silicon photovoltaic curtain wall module that integrated into Kawneer's standard curtain wall system and commercialized and is sold through Kawneer's network of salesman and dealers. During PV:BONUS One, a potential demand for a Building-integrated Photovoltaic (BIPV) product based on thin film PV modules was identified. Advantages of using thin film PV modules in BIPV applications include: 1) cosmetics; 2) lower cost per unit of area than crystalline modules; and potential for a controlled amount of light transmission through the module. Under PV:BONUS Two, Solarex supported by Kawneer, SDA, and Velux, propose to develop BIPV products including curtain walls, skylights and sunshades using tandem junction amorphous silicon plates now being produced by Solarex in its Toano, VA factory. The commercial products will be developed in conjunction with Kawneer, mounting directly into Kawneer curtain wall framing and installed by glazers using the same methods used to install curtain walls. The residential products will be developed in conjunction with Velux, a major worldwide manufacturer of skylights, for installation directly into the skylights and roof windows manufactured in the Velux factory in South Carolina.

**Status/Accomplishments:** Solarex, competitively selected, was awarded Phase 2 funding July, 01, 1998 for continued development of these three thin film PV products. During Phase 1, Solarex reduced the number of products developed under PV:BONUS Two from five to three and completed conceptual designs on each.

**Planned FY 1999 Milestones:** During FY99, the Solarex team plan to: complete feasibility and cost analyses; develop prototypes of each of the three products; conduct testing; initiate pilot production; and develop market entry strategies for the each of the products.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - Flame Retardant PV Module Encapsulants

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| **Agreement#:** DE-FC36-97GO10255 | **Project Period:** 9/30/97–06/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | Springborn Testing & Research, Incorporated<br>10 Water Street<br>Enfield, CT 06082 | |
| | **Organization Type:** IN | **Congressional District:** 6 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>James Galica<br>**Phone:** 860-749-8371 **Fax** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Springborn Testing & Research, Incorporated |
| | **DOE Funding Allocation:**<br>1997: $49,960<br>1998: None | **Cost Share Funding:**<br>1997: $12,973<br>1998: None |

**Project Objective:** Springborn Testing and Research, Inc. to develop and commercialize a line of fire retardant encapsulation materials to serve the emerging building integrated and building mounted PV market. The major technical objective is to develop and commercialize a line of fire retardant encapsulation materials to serve the emerging building integrated and building mounted PV market. The product concept is a line of fire retardant encapsulants, e.g. **PhotoCap FR,** to be developed and marketed specifically for the BIPV market. The line will likely comprise optically clear flame retardant encapsulants for over the cells and more highly filled grades with superior fire retardancy for behind the cells. The latter would likely be laminates of FR EVA, moisture barrier, and intumescing/insulating layer.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. Springborn Testing & Research, Incorporated was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the flame retardant PV module encapsulant concept was developed. Springborn Testing & Research completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

# PV:BONUS Two - Window Quality Transparent Photovoltaic Glazing Products

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| **Agreement#:** DE-FC36-97GO10259 | **Project Period:** 9/30/97–06/30/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King **Phone:** 202-586-1693 **Fax:** 202-586-8148<br>R. Hassett **Phone:** 202-586-8163 **Fax:** 202-586-8148 | TerraSun, LLC<br>4541 S. Butterfield Drive<br>Tucson, AZ 85714 | |
| | **Organization Type:** IN | **Congressional District:** 2 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>George Mignon<br>**Phone:** 520-512-1995 **Fax** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>TerraSun, LLC |
| | **DOE Funding Allocation:**<br>1997: $40,000<br>1998: None | **Cost Share Funding:**<br>1997: $124,406<br>1998: None |

**Project Objective:** TerraSun L.L.C., a Tucson Arizona based development company, proposes to developed a window quality transparent photovoltaic technology with applications as a Building-integrated PV module. TerraSun is jointly submitting this request for funding in the PV BONUS program with Viracon, a leading producer of high performance glazing products for buildings.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. TerraSun was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the window quality transparent photovoltaic glazing product concept was developed. TerraSun completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - Field Applied PV Membrane

| **Agreement#:** DE-FC36-98GO10249 | **Project Period:** 9/30/97–09/30/02 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | United Solar Systems Corporation (USSC)<br>1100 West Maple Road<br>Troy, MI 48084 | |
| | **Organization Type:** IN | **Congressional District:** 12 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Dr. Sebhendu Guha<br>**Phone:** 248-362-4170 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>United Solar Systems Corporation (USSC) |
| | **DOE Funding Allocation:**<br>1998: $213,205 | **Cost Share Funding:**<br>1998: $214,800 |

**Project Objective:** United Solar Systems Corp. in collaboration with Energy Conversion Devices Inc. the National Association of Home Builders, Phasor Energy, Arizona Public Service, Southern California Edison Co., Southern Cal Roofing, ATAS International, Elk Corp and San Diego Gas & Electric intend to develop a field applied, flexible photovoltaic (PV) membrane product for the 'built-environment". The UNI-SOLAR PV Membrane, a flexible PV laminate, will ship directly to the site for field application or to a building product company for integration with their own products. It uses United Solar multi-junction a-Si stainless steel PV cells laminated in flexible UL approved materials.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding of which United Solar System Corporation was one. The activities to be undertaken in Phase 2 include: 1) product development and testing; 2) market planning; and 3) business development. For the commercial sector, a 250 watt, 30" x 18' PVM design is planned for retrofitting onto flat commercial roofs and existing metal roof shade structures (covered parking). For residential and light commercial markets with sloped roofs, a narrower 125 watt, 16" x 18', PVM is needed for conform to conventional metal roofing shapes. For concrete tile roofs, prevalent in the southwest, the 125 watt PVM will be designed as a PV "Shingle Membrane" for use in an integrated manner with flat tiles.

**Status/Accomplishments:** The conceptual design of the product has been completed and key product development tasks identified including PV Membrane size, electrical characteristics, termination designs, mounting methods for flat commercial roofs, covered parking, metal and tile shingle roofs. The PVM uses United Solar Triple-Junction PV cells on a flexible substrate, laminated in UL approved weather resistant materials to provide a flexible PV "membrane".

**Planned FY 1999 Milestones:** Based on Phase 1 product conceptual design, market assessment and business strategies, the team will complete the product development and testing, produce the marketing plan, and develop the business strategies and relationships needed for full commercialization. Key product development tasks include defining an optimal set of PV Membrane sizes, termination/wiring design, module fabrication processes, and field installation designs for metal roofing, facades, and commercial flat EPDM membrane roofing. A quantity of prototype PVM will be produced for field testing bonding methods, termination design and appearance. Standard designs will be developed and between two and four demonstration systems for field testing will be identified.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## Building-Integrated Photovoltaics

# PV:BONUS Two - PVT: a Photovoltaic/Thermal Concentrator Total Energy System

| **Agreement#:** DE-FC36-97GO10253 | *Project Period:* ***9/30/97–06/30/98*** |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King R. Hassett<br>**Phone:** 202-586-1693 **Phone:** 202-586-8163<br>**Fax:** 202-586-8148 **Fax:** 202-586-8148 | United Solar Technologies Corporation<br>6503 81st Street<br>Cabin John, MD 20818 | |
| | **Organization Type:** IN | **Congressional District:** 8 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Carlo La Porta<br>**Phone:** 301-229-0671 **Fax** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>United Solar Technologies Corporation |
| | **DOE Funding Allocation:**<br>1997: $49,795<br>1998: None | **Cost Share Funding:**<br>1997: $13,006<br>1998: None |

**Project Objective:** United Solar Technologies, Inc. and its partnering firm Industrial Solar Technology Corporation for the development of a photovoltaic/thermal (PVT) cogeneration system. The purpose of Phase 1 is to assess in detail the product concept in order to prepare the detailed plans required for commercialization of United Solar Technologies' 2400:1 parabolic dish output from the dish into an appropriate electrical service box.

**Approach/Background:** The objective of the PV:BONUS Two solicitation, issued April 2, 1997, is for the development of commercial building products through three phases as follows: 1) concept development and business planning; 2) product and business development; and 3) product demonstration and marketing. Under Phase 1, sixteen Cooperative Agreement were awarded for a Phase 1 duration of nine months (September 30, 1997 through June 30, 1998). A total of seven projects were competitively selected for Phase 2 funding. United Solar Technologies was not selected for continued funding under Phase 2.

**Status/Accomplishments:** Under Phase 1, the photovoltaic/thermal (PVT) cogeneration system concept was developed. United Solar Technologies completed Phase 1 activities June 1998, but was not selected for continued funding by the Merit Review Committee.

**Planned FY 1999 Milestones:** none

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

**PV for Utility Applications**

**PV Projects for States**

| **Contract #:** AJ-5385 and AU-8437 | **Contract Period:** 6/11/92–AU-8437 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | **Principal Investigator (s)** |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | **AU-8437B**<br>Community Office for Resource Efficiency<br>Aspen, CO<br><br>**AU-8437F**<br>Energy Ideas/Potomac Region Solar Energy Assoc.<br>Kensington, MD<br><br>**AU-8437H**<br>Empire Electric Co.<br>Joplin, MO<br><br>**AU-8437D**<br>Montana Dept. of Environmental Quality<br>Helena, MT<br><br>**AU-8437E**<br>Oregon Office of Energy<br>Salem, OR<br><br>**AU-8437**<br>Rio Grande Nature Center<br>Albuquerque, NM<br><br>**AU-8437C**<br>Wisconsin Dept. of Natural Resources<br>Madison, WI | R. Udall<br>**Phone:** 970-544-9808<br>**Fax:** (970) 544-9599<br><br>J. McCabe<br>**Phone**: 301-530-1473<br>**Fax**: (301) 530-1473<br><br>R. Johnson<br>**Phone:** 417- 625-5169<br>**Fax:** 417-625-5169<br><br>C. White<br>**Phone:** 406-444-6780<br>**Fax:** 406-444-6836<br><br>J. Klure<br>**Phone:** 503-373-1581<br>**Fax:** 503-373-7806<br><br>K. Brown<br>**Phone:** 505-344-7240<br>**Fax:** 505-344-4505<br><br>L. Krom<br>**Phone:** 608-266--823<br>**Fax:** 608-266-2750 |
| | **Organization Type**: | **Congressional District:** |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| **Technical Monitor:**<br>R. Hill<br>**Phone:** 505-844-6111<br>**Fax:** 505-844-6541 | **DOE Funding Allocation:**<br>1996: $100,000<br>1997: $0<br>1998: $0 | **Cost Share Funding:** |

**Project Objective:** To introduce photovoltaics to agencies, utilities, and other organizations that have a strong likelihood of benefiting from the use of PV.

**Approach/Background:** Through developmental or pilot projects, these organizations will have and will document a positive experience with PV so that others might gain information that will assist them in further PV projects.

**Status/Accomplishments:** Installations of all projects were completed. These installations and others will be compiled in a Sandia publication in Fall, 1998.

**Planned FY 1999 Milestones:** Each contract will issue a final report after the installation is complete.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

# Million Solar Roofs Community Partnership Planning, Coordination, Education, and Infrastructure Development for the City of Albuquerque

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|---|---|
| **Contract #:** RBW 8-18667-01 | **Contract Period:** 6/98 to 6/99 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | City of Albuquerque Development Services Division<br>2708 Central SW<br>Albuquerque, NM 87104 | |
| | **Organization Type**: IN | **Congressional District:** 1 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Kim Kalender<br>**Phone:** 505-764-0037 **Fax:** (505)764-1782 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $25,000 | **Cost Share Funding:** |

**Project Objective:** This subcontract is directed towards community partnership development activities for the Million Solar Roofs Initiative (MSRI) implementation. The MSRI plans to install one million solar thermal and photovoltaic installations on US buildings by 2010. The plan is to accomplish this through community partnership teams, which may involve the utility/energy service provider, industry (building/solar), state and local governments and other potential stakeholders. The MSRI community teams will coordinate planning education, business alliances, value analysis and infrastructure development to identify the participation approach which best fits the community needs. This flexible approach to implementation of the MSRI should allow the community teams to create a solar technology commercialization plan of highest value and therefore highest potential for sustainability beyond the initiative.

**Approach/Background:** The City of Albuquerque plans to use an infill, mixed income, sustainable development as the basis for infrastructure and public outreach.

**Status/Accomplishments:** The City has held design charettes and public meetings.

**Planned FY 1999 Milestones:** The City is planning a workshop to educate city agencies in Feb1999. Additionally, the City is developing a Million Solar Roofs initiative plan.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

# Utility On-Grid Photovoltaic Applications

| **Agreement#:** DE-FC36-94GO10007 | **Project Period:** 8/16/94–12/31/01 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>D. Ton — **Phone:** 202-586-4618 — **Fax:** 202-586-8148 | Edison Technology Solutions<br>6040 N. Irwindale Avenue<br>Irwindale, CA 91702 | |
| | **Organization Type:** IN | **Congressional District:** 28 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Jim Reilly<br>**Phone:** 626-815-0501 **Fax** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Edison Technology Solutions |
| | **DOE Funding Allocation:**<br>1993: None — 1996: $500,000<br>1994: $500,000 — 1997: None<br>1995: $1,500,000 — 1998: None | **Cost Share Funding:**<br>1993: $500,000 — 1996: None<br>1994: $2,000,000 — 1997: None<br>1995: None — 1998: None |

**Project Objective:** The major objective of the SCE program is to validate the use of PV as a circuit-specific peaking support resource. The ultimate benefit of a successful on-grid PV program would be more rapid commercialization of the potentially large domestic on-grid PV market.

**Approach/Background:** The proposed application involves using PV to meet peak load requirements on selected SCE electric distribution circuits. The circuits of interest are old, underground 4 kV circuits which have reached the limit of their load-carrying capability. The circuits serve residential areas which have seen recent growth in peak load requirements so that the circuits will soon exceed their limit during the summer peak load period. Without PV, the main alternative is to replace the circuits by excavating city streets and landscaping to install new underground, high-capacity cable. Since SCE estimates that the replacement of underground cable costs approximately $600,000 per mile, installing PV to meet the peak load requirements on these circuits results in the deferment of this significant cable replacement expense. SCE estimated that replacement of about 200 miles of underground 4 kV circuits in their system could be deferred by the use of grid-connected PV. This would require approximately 25 MW of PV to meet the peak loads on these circuits. The program has been proposed in two separate phases. In Phase I, a feasibility assessment would be performed to address issues such as load and solar resource coincidence, load growth, alternatives to PV, and the size, scope, configuration, and available roof space for PV systems. Some initial installation and testing would also be performed on a pilot scale to establish data for the areas to be considered for the project. Phase II would include the final design, procurement, installation, and monitoring stages.

**Status/Accomplishments:** Maintenance and data collection continued for the following sites: 1) covered reservoir (98.3 kW) at Huntington Library; 2) rooftop application (112 kW) at Monterey Hills Elementary School; and 3) patio cover (5.76 kW) at University of California, Irvine. Construction was completed for the following: 1) covered lunch/assembly area (12.6 kW) at Alamitos Intermediate School located in Orange County, CA; 2) covered lunch/assembly area (10.9 kW) at Glenmeade Elementary School; 3) rooftop systems (31.5 kW) at Knotts Berry Farm Amusement Park; and 5) Pacific Park solar Ferris Wheel (49.5 kW).

**Planned FY 1999 Milestones:** Continue monitoring and data collection and document results.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

# Community Education, Outreach and Value Identification for the Greater Flagstaff Area

| **Contract #:** RBW 8-18672-01 | **Contract Period:** 6/98 to 6/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | The Greater Flagstaff Economic Development Council<br>1300 South Milton Rd., Suite #125<br>Flagstaff, Arizona, 86001-7302 | |
| | **Organization Type**: IN | **Congressional District:** 6 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Kim Poirier<br>**Phone**(800) 595-7658 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>Arizona Public Service<br>Coquina County Board of Supervisors<br>AZ Dept. of Commerce<br>Multiple industry sponsors |
| | **DOE Funding Allocation:**<br>1998: $15,000 | **Cost Share Funding:**<br>1998: $25,000 |

**Project Objective:** The State of Arizona developed an efficiency and renewable energy economic development scenario analysis in 1997, which was the basis for Flagstaff's identifying renewable energy as an economic development target cluster industry. Actual community value metrics are expected as this community work develops.

**Approach/Background:** The mission of the Greater Flagstaff Economic Council, Inc. (GFEC) is to improve the economic well being and opportunity for the citizens of the greater Flagstaff area. The Southwest Energy Fair supports that mission in two distinct arenas, education and economic development.
*Education.* The fair promotes the use of economic, ethical, and environmentally sound power alternatives and energy efficient practices through education, demonstration, and participation. There is a tremendous need for alternative power and environmental technology services on the 20 Native American reservations and throughout Arizona.
*Economic Development*. GFEC has identified renewable energy for a target cluster based economic development strategy as part of our 3 year strategic plan. The Southwest Energy Fair is intended to be a part of the 3 year plan to recruit from this industry cluster.
*Community Benefit.* The economic growth will spur the creation of full-time career opportunities with above average wages and basic fringe benefits, resulting in a higher standard of living and an improved quality of life for the citizens. Because most people locate in Flagstaff to enjoy the beauty of the nature that surrounds us, Coconino County and the Native Americans are environmentally sensitive, valuing and seeking to protect the natural resources given us. The community will benefit by having like-minded companies here that are excellent corporate citizens, possess a good environmental record, and are concerned with preserving the environment as well.
**Status/Accomplishments: The** fair was a success.

**Planned FY 1999 Milestones:** The economic development council is developing a report.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV for Utility Applications

# Million Solar Roofs Community Partnership Planning for the Island of Hawaii

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|---|---|
| **Contract #:** RBW 8-18664-01 | **Contract Period:** 6/98 to 6/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Hawaii Electric Light Company<br>1200 Kiluaea Avenue<br>Hilo, HI 96720 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Steve Burns<br>**Phone**(808)969-0136 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $25,000 | **Cost Share Funding:** |

**Project Objective:** This subcontract is directed towards community partnership development activities for the Million Solar Roofs Initiative (MSRI) implementation. The MSRI plans to install one million solar thermal and photovoltaic installations on US buildings by 2010. The plan is to accomplish this through community partnership teams, which may involve the utility/energy service provider, industry (building/solar), state and local governments and other potential stakeholders. The MSRI community teams will coordinate planning education, business alliances, value analysis and infrastructure development to identify the participation approach which best fits the community needs. This flexible approach to implementation of the MSRI should allow the community teams to create a solar technology commercialization plan of highest value and therefore highest potential for sustainability beyond the initiative.

**Approach/Background:** Hawaii Electric Light Company, Inc (HELCO) has been a leader in the commercialization of solar technology in the state of Hawaii and specifically in the County of Hawaii. They will therefore take the lead in this partnership development project.

- Identify the community partnership team.
- Request a short statement from each team member, identifying or proposing the individual's, company's, or government entity's responsibilities and activities for the long-term (through 2010) MSR program on the big island of HI.
- Merge these statements into a document to be the initial MSR plan for the Big Island
- Identify the coordinating committee for the Hawaii Island Million Solar Roofs Kick-off Project (a subset of the community partnership team.
- Explore additional funding for the project
- Make recommendations on appropriate sites for the exhibit
- Develop a design concept and education and outreach approach for the exhibit

**Status/Accomplishments:** HELCO has completed the plan.

**Planned FY 1999 Milestones:** The stakeholders will be working on the exhibit.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV for Utility Applications

# Photovoltaics for Utilities (PV4U)

| **Contract #:** FG41-94R110638 | **Contract Period:** 4/20/94–4/30/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Interstate Renewable Energy Council<br>P.O. Box 1156<br>Latham, NY 12110 | |
| | **Organization Type**: NP | **Congressional District:** 21 |
| **Directing Organization**:<br>Department of Energy, Boston Support Office<br>One Congress Street<br>Boston, MA 02144 | **Principal Investigator (s)**<br>J. Weissman<br>**Phone:** 617-232-7377 **Fax:** 617-325-6738 | |
| **Technical Monitor:**<br>R. Michaud<br>**Phone**: 617-565-9713<br>**Fax**: 617-565-9723 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1994: $400,000 1997: $600,000<br>1995: $400,000 1998: $600,000<br>1996: $600,000 | **Cost Share Funding:** |

**Project Objective:** Organize and support state level associations to promote utility connected photovoltaic applications, and to supply those state associations with information in order to accelerate the commercialization of photovoltaics through the utility sector.

**Approach/Background:** The Interstate Renewable Energy Council (IREC) works to accelerate the sustainable utilization of renewable energy sources and technologies in and through state and local government activities. The Photovoltaics for Utilities Program represents an alliance of states that have established collaborative forums to accelerate the commercialization of photovoltaics. PV4U State Working Groups identify regulatory, policy, and institutional barriers to PV deployment and develop strategies to overcome these hurdles.

**Status/Accomplishments:** Fourteen states have active PV4U Working Groups where representatives from regulatory commissions, utility companies, the solar industry state and federal government agencies, consumer groups, and advocacy organizations, meet to work on policy and market barriers. Three states are part of the PV4U Alliance but have been less active due to the closing of an energy office and changes in leadership.

**Planned FY 1999 Milestones:** Produce the quarterly "Connections Newsletter," the monthly mailings to state coordinators.

**Major Reports Published in FY 1998:**
PV4U Connections Newsletter (biannually).
PV4U Connections Clearinghouse and Bibliography Services (biannually).
Connecting PV to the Utlity Grid.
Renewable Energy Focus.
PV4U Consumer Letter (quarterly).
NASUCA PV Training Manual (1996).

**Major Articles Published in FY 1998:**
None.

## PV for Utility Applications

# Solar Policy Forums

| **Contract #:** ACU-7-16823 | **Contract Period:** 6/97 to 8/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Interstate Renewable Energy Council (Irec)<br>P.O. Box 1156<br>Latham, NY 12110-1156 | |
| | **Organization Type**: IN | **Congressional District:** 21 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Vicki Maistitis<br>**Phone:** 617/323-7377 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1997: $65,000<br>1998: $10,000 | **Cost Share Funding:** |

**Project Objective:** This subcontract is directed towards educating community stakeholders on the benefits and impacts of solar energy technology deployment. As utilities transition into the competitive arena, communities will consider energy as an additional infrastructure planning element to assure continued societal benefits which may be jeopardized by deregulation. The education forums will be directed towards communities active in energy policy development and communities needing additional information on the value of renewables. The information will be tailored and formatted for developing energy elements for growth management policies. Each forum, or workshop, will provide the information to assure the developed policies maximize the benefits of solar technologies.

**Approach/Background:** There is a need for more in-depth discussion of the economics, impacts, and practical application of renewable energy issues and policies. There is also a desire to bring more stakeholders into the discussions and to develop a community-based consensus for solar policy. Additionally, communities need a platform for sharing information, and the format of the forums will provide this opportunity.

**Status/Accomplishments: Over** forty communities attended two separate forums, one forum provided extensive information to the communities and the second forum, a year later, required the communities to prepare presentations for an interaction type format

**Planned FY 1999 Milestones:** Subcontract is completed, however activity continues within individual communities and community workshops are continually supported through the labs and lab subcontractors.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
*NCPV Photovoltaics Program Review; Proceedings of the 15th Conference, Denver, CO, 1998;* AIP Conference Proceedings (in press) [if appropriate]

## PV for Utility Applications

# Development of the Tucson Photovoltaic Coalition to Promote & Support Photovoltaic Installations

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|---|---|
| **Contract #:** RBW 8-18685-01 | **Contract Period:** 6/98 to 6/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Learning Village Project<br>Post Office Box 42708<br>Tucson, AZ 85733 | |
| | **Organization Type**: IN | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Valerie Rauluk and David Fuller<br>**Phone**(520) 326-3195 **Fax:** (520) 326-3195 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $25,000 | **Cost Share Funding:** |

**Project Objective:** This subcontract is directed towards community partnership development activities for the Million Solar Roofs Initiative (MSRI) implementation. The MSRI plans to install one million solar thermal and photovoltaic installations on US buildings by 2010. The plan is to accomplish this through community partnership teams, which may involve the utility/energy service provider, industry (building/solar), state and local governments and other potential stakeholders. The MSRI community teams will coordinate planning education, business alliances, value analysis and infrastructure development to identify the participation approach which best fits the community needs. This flexible approach to implementation of the MSRI should allow the community teams to create a solar technology commercialization plan of highest value and therefore highest potential for sustainability beyond the initiative.

**Approach/Background:** The following activities and planned for the Tucson coalition:

1. Facilitate membership in TPVC and establish mission, objectives, and operating structure.
2. Establish a Buying Cooperative for Photovoltaic devices for installers, developers, and contractors in the region.
3. Establish relationships with funding authorities for more efficient financing of solar devices.
4. Research and recommend best possible structures for a Community Energy Cooperative or Energy Service Organization which supports wide-spread dissemination of PV technologies and other solar devices (solar thermal, especially solar water heaters).
5. Solidify the inclusion of renewable energy and sustainability criteria for programs, policies, and projects at the local government level, in particular, the City of Tucson and Pima County.

**Status/Accomplishments:** All activities have been completed

**Planned FY 1999 Milestones:**

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV for Utility Applications

# Renewable Energy Applications and Economic Analysis for Electric Power

| **Contract #:** AAX-5-15330-01 | **Contract Period:** 8/23/95–12/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Pacific Energy Group<br>32 Valla Court<br>Walnut Creek, CA 94596 | |
| | **Organization Type**: IN | **Congressional District:** 10 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>H. Wenger<br>**Phone:** 925-937-1750 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>Pacific Energy Group. |
| | **DOE Funding Allocation:**<br>1995: $120,000<br>1997: $167,000<br>1998: $85,000 | **Cost Share Funding:**<br>1998: $50,000 |

**Project Objective:** The objective of this work is analysis of PV applications, financials, and market opportunities in the changing electric service provider environment.

**Approach/Background:** This subcontract has developed broad-based analysis for financial risk valuation of utility investments, customer sited PV value, policy value, and alternative electric service provider operating scenarios. The broad-based analysis has then been targeted to regions, states, municipalities, utilities and consumers for the purpose of identifying values and developing markets.

**Status/Accomplishments:** Analyzed financial "Risk Management Using Renewable Energy Attributes" for a variety of electric power investment scenarios; developed user-friendly software for distributed utility valuation; provided initial analyses of "Niche Markets for Grid-Connected Photovoltaics" (residential) and an architects perspective for market deployment of building integrated PV; provided analyses of commercial building integration value and microgrid and load leveling strategies. Developed a more detailed report on the initial niche market analysis approach; expand and detail the niche market analysis to include additional application and customer segmentation; analyze the financial community's view of the electric industries' investment in renewables and the effects on specific company financial status; determine the state revenue impact for legislation and policies which favor renewable deployment; support the Million Solar Roofs Initiative; provide custom analysis for the electric industry, state energy offices, legislatures, regulatory commissions, and consumer advocates as requested; and apply risk management financial analysis to actual utility case studies.

**Planned FY 1999 Milestones:** Subcontract has ended.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
"Distributed Generation and Micro-Grids" T. E. Hoff, H. J. Wenger, C. Herig, and R. W. Shaw, Jr. 18th USAEE/IAEE, (September 1997).
Integrating Renewable Energy Technologies in the Electric Supply Industry: A Risk Management Approach
T. E. Hoff, National Renewable Energy Laboratory (July 1997).
"Policy Options to Accelerate Grid-Connected PV Markets," H.J. Wenger and C.P. Herig, ASES Solar 97, Washington, DC.

# PV for Utility System Applications (PVUSA)

| | |
|---|---|
| **Contract #:** DE-FC04-96AL89744, A002 | **Contract Period:** 10/1/96–9/30/99 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Sacramento Municipal Utility District<br>P.O. Box 15830<br>Sacramento, CA 95852-1830 | |
| | **Organization Type**: ST | **Congressional District:** 3 |
| **Directing Organization**:<br>DOE/AL/TDD<br>P.O. Box 5400<br>Albuquerque, NM 87185 | **Principal Investigator (s)**<br>D.E. Osborn<br>**Phone:** 916-452-3211 | |
| **Technical Monitor:**<br>D. Sanchez<br>**Phone**: 505-845-4417 | **B&R Code**: EB22 | **Cost Share Information**:<br>Sacramento Municipal Utility District |
| | **DOE Funding Allocation:**<br>1998: $600,000 | **Cost Share Funding:**<br>1998: $640,000 |

**Project Objective:** To operate the PVUSA facility, collect and analyze data from approximately 20 large-scale and/or rooftop-class grid-connected PV systems. These systems are located at the PVUSA facility in Davis, California, and at eight other locations around the United States. The project makes information and data collected from grid-connected operations available to the PV industry, including operators, utilities, manufacturers, and those providing infrastructure in support of PV. Key aspects of this program include transfer of technical data through presentations at industry forums and through presentations at workshops, as well as support for the development of codes and standards appropriate to the commercialization of distributed PV generation.

**Approach/Background:** The focus during this Cooperative Agreement is on grid-connected, distributed PV, typically "rooftop" class systems. PVUSA will continue to operate and evaluate the performance of the assigned earlier generation of large PV systems, but only to the extent that the effort does not distract from the need to support and assess the performance and operation of the current generation of PV systems. Using these new facilities to provide the initial training of PV service workers, installers, inspectors and designers is intended to accelerate the acceptance and maturity of the PV industry. Analysis and directed testing of PV systems, including the critical PCUs, is being done to validate the needed codes and standards being developed and applied to PV systems.

**Status/Accomplishments:** During FY 1998, PVUSA accomplished all of its committed goals, and exceeded in both quality and quantity many of the specifics. In particular, Phase II of the Small System Test Center was commissioned, bringing to six the number of full-scale (4-kW class) PV systems being monitored and operated. These are the systems available to students attending the PVUSA-provided workshops, and upon which we are testing many of the provisions and requirements of new codes and standards. The objective of bringing in new and significant sources of funding to match the DOE agreement made significant progress. This includes winning a California Energy Commission competitive PIER-1 award for $350,000, a CEC grant of $200,000, fees for services rendered of approximately $75,000, as well as new dues-paying members.

**Planned FY 1999 Milestones:** Implement the programs committed to project sponsors, in particular those associated with the California Energy Commission PIER-1 contract for the PUC Test Center, while meeting the considerable demand for developing training materials and presentation of workshops. At the same time, the project will continue to collect and disseminate the valuable data being acquired on the wide range of PV systems now in its database.

**Major Reports Published in FY 1998:**
Quarterly and Annual Reports of system performance and experience. Report on the upgrade and refurbishment of the Maui Grid Tied System.

**Major Articles Published in FY 1998:**

## PV for Utility Applications

# Solar Resource Utility Load-Matching Assessment

| **Contract #:** XR-1-11168-1 | **Contract Period:** 9/20/91–2/19/96 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | State University of New York<br>Albany, NY 12222 | |
| | **Organization Type**: IN | **Congressional District:** 21 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>R. Perez<br>**Phone:** 518-432-8751 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>State University of New York. |
| | **DOE Funding Allocation:**<br>1994: $59,141 — 1997: $0<br>1995: $49,974 — 1998: $60,000<br>1996: $40,000 | **Cost Share Funding:**<br>1996: $100,000 |

**Project Objective:** The objective is to apply the techniques demonstrated in New York to a broad cross section of utilities located in various regions of the United States. To determine the capacity value of PV and apply to valuation techniques from both the utility and consumer perspective.

**Approach/Background**: In this current cost extension, the State University of New York will continue to 1) Perform solar resource load match assessment for utilities, subsystems, or customers as requested; 2) Develop niche market/commercial building analysis PV; 3) Coordinate with other NREL utility related subcontracts by providing requested data; and 4)Develop a prototype PV/load matching controller.

**Status/Accomplishments:** In the previous phases of this subcontract, a capacity value for PV was identified through the solar resource load matching of over 109 load years of data. This greatly increases the valuation of PV as a generating technology to utilities. Additional key findings include: 1) PV capacity may be significant outside traditional high solar resource regions; 2) ELCC is not correlated well with solar resource; and 3) ELCC is correlated with load shape characteristics. Addressed the evolving competitive utility industry and examined both customer class and seasonal variations of the ELCC. The commercial building analysis was completed. The prototype controller is currently being tested.

**Planned FY 1999 Milestones:** Test market solar load controller and expand commercial niche market analysis.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:**
"Valuation of Demand-Side Commercial PV Systems in the United States," ASES '98, Albuquerque, NM, June 1998.

## PV for Utility Applications

# User-Scale Applications - Photovoltaics (USAPV)

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| **Agreement#:** DE-FG36-93CH10587 | **Project Period:** 9/27/93–6/30/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>D. Ton — **Phone:** 202-586-4618 — **Fax:** 202-586-8148 | User-Scale Applications - Photovoltaics<br>One Upper Pond Road<br>Parisippany, NJ 07054 | |
| | **Organization Type:** IN | **Congressional District:** 11 |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Jim Thorpey<br>**Phone:** 973-263-6376 **Fax:** | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>User-Scale Applications - Photovoltaics |
| | **DOE Funding Allocation:**<br>1993: None — 1996: None<br>1994: $352,740 — 1997: None<br>1995: $303,864 — 1998: None | **Cost Share Funding:**<br>1993: None — 1996: None<br>1994: $352,740 — 1997: None<br>1995: $658,030 — 1998: None |

**Project Objective:** The prime objectives of the USAPV program is three fold as follows: 1) develop the necessary marketing business plans and regulatory framework to integrate photovoltaic technology into the portfolio of products and services offered by the utility, 2) develop the necessary standards for and understanding of PV technology such that PV becomes one of several solutions employed by utilities to solve operational problems and meet distribution system peak demands, and 3) introduce at least 10 MW of new PV demand within the northeastern United States.

**Approach/Background:** USAPV was originally proposed and sponsored by Congressman Dean Gallo (R-NJ) as a program that would encourage greater visibility and opportunity for the integration of PV technology in New Jersey and the northeastern United States. The New Jersey Board of Regulatory Commissioners (NJBRC) has been in the forefront of regulatory reform in the promotion of demand side management programs and is an advocate of PV applications in New Jersey. Both the NJBRC and NJDEPE strongly support and endorse the project. Furthermore, regulatory support may promote a broader acceptance and visibility for this PV initiative in the utility industry. User Scale Applications - Photovoltaics (USAPV) will implement cost shared demonstrations of utility-owned, end-user and distributed applications of photovoltaic technology. USAPV's objective is to leverage federal funds with private funding from utilities customers, PV industry, state regulatory agencies, and other participating organizations. USAPV will monitor and evaluate projects, each cost-shared on a minimum of a 50/50 basis. USAPV will establish priorities for demonstration projects and will be responsible for their management, data collection and reporting. USAPV will be managed by a Steering Committee with representation from the participating utilities, New Jersey Department of Environmental Protection and Energy (NJDEPE), and U.S. DOE with advisement from a Technical Review Committee representing PV experts from National Laboratories and utilities, industry, and research organizations.

**Status/Accomplishments:** Projects were initially sponsored by Jersey Central Power & Light and Atlanta Electric who cost shared on a 50/50 basis for the implementation of projects in the areas of fluorescent and outdoor lighting, and isolated load applications. Four projects have been completed through those two utilities with an additional five planned or underway. Additionally, three utilities have submitted proposals for the implementation of another five applications, which were approved for grants from USAPV. The utilities, each acting as project manager for their specific project, are Metropolitan Edison Company, Potomac Electric Power Company, and New York Power Authority. Furthermore, two additional projects, proposed by Taunton Municipal Lighting Plant and Tampa Electric Company were submitted and subsequently proposed for funding through USAPV.

**Planned FY 1999 Milestones:** Complete all installations and submit final report.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## PV for Utility Applications

# Technology Experience to Accelerated Markets in Utility Photovoltaics (TEAM-UP)

| **Agreement#:** DE-FC36-93CH10560 | **Project Period:** 10/1/92–12/31/98 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King, **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>D. Ton, **Phone:** 202-586-4618, **Fax:** 202-586-8148 | Utility Photovoltaic Group (UPVG)<br>1800 M Street, N.W., Suite 300<br>Washington, DC 20036-5802 | |
| | **Organization Type:** IN | **Congressional District:** AL |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Jeffrey Serfass<br>**Phone:** 202-857-0898 **Fax:** 202-223-5537 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:**<br>Utility Photovoltaic Group (UPVG) |
| | **DOE Funding Allocation:**<br>1993: $800,000 1996: $5,400,054<br>1994: $1,000,000 1997: $300,000<br>1995: $8,891,000 1998: $2,000,000 | **Cost Share Funding:**<br>1993: $193,000 1996: $19,018,482<br>1994: $209,000 1997: $1,056,573<br>1995: $22,471,131 1998: $1,706,738 |
| | | |

**Project Objective:** The Utility PhotoVoltaic Group's (UPVG's) objectives is the establishment of an accelerated market for suppliers of photovoltaic systems that allows investments in larger manufacturing facilities, thus reducing photovoltaic unit costs through economies of scale, creating even broader market potential. TEAM-UP, a multi-year, 50 MW hardware initiative, provides for small-scale applications and grid-connected programs, as well as, focusing on commercialization strategies for photovoltaic systems in the utility industry. The prime objective of TEAM-UP is achieving sustained, domestic PV commercialization by the year 2000.

**Approach/Background:** Created in September 1992, the Utility PhotoVoltaic Group's original Program Development Plan addressed the large potential for applications of photovoltaic systems for electric utilities and their customers. The first activity focused on technology transfer and promotion to accelerate today's potential economic applications of photovoltaic systems for the benefit of electric utilities and their customers, while the other parallel program was the formulation and exploitation of strategies that would result in high-volume purchases of photovoltaic systems for emerging applications. Phases 1 and 2 of the agreement focused on these two parallel activities, whereas Phase 3 includes the implementation of utility market acceleration strategies.

Implementation of UPVG's hardware initiative, TEAM-UP, began during Phase 3 with funding for grid-connected projects and support of market/buyer teams for grid-independent applications. During Phase 3, twelve (12) grid-connected projects were initiated and will result in 5.9 MW of photovoltaic installations valued at $32 million. Additionally, UPVG was instrumental in securing funding either through TEAM-UP or other sources for more than 80% (21 projects) of the 26 proposals received in response to the grid-connected applications (GCA) Request for Proposals issued in December 1994. Five teams were formed which will serve as market development and/or buyer teams for six (6) off-grid applications of photovoltaics, including remote residential service, water pumping applications, and lighting applications. The 1994 and 1995 TEAM-UP RFP's (Round One and Round Two) led to 23 agreements for efforts with a total value exceeding $53.6 million and will result in more than 1,300 PV systems being installed in 35 utility service areas around the United States. Over 8.2 MW of new PV system capacity will result from these efforts.

**Status/Accomplishments:** The 1997 TEAM-UP Request for Proposals (RFP) for cost-shared, grid-connected and grid-independent ventures was issued on October 3, 1997. A total 14 ventures were awarded FY98 funding under Round 3 of the TEAM-UP program. The Phase 5 program focused on four task areas: 1) expanding PV technology experience base; 2) increasing PV business opportunities and markets; 3) supporting the community/city buildings initiative; and 4) education, communication, and promotion.

**Planned FY 1999 Milestones:** Continue funding cost-shared grid-connected and grid-independent ventures under the 1997 TEAM-UP Request for Proposals and continue technical and financial monitoring and documentation of the existing 28 TEAM-UP ventures.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

## PV for Utility Applications

# Coordination and Development of the Washington 5,000 Solar Rooftops by 2005 Collaborative

| **Contract #:** | **Contract Period:** 6/98 to 6/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693, **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455, **Fax:** 202-586-8148 | Washington State University Energy Program<br>925 Plum Street, SE, Building 4<br>P. O. Box 43165<br>Olympia, WA 98504-3165 | |
| | **Organization Type**: IN | **Congressional District:** 3 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Mike Nelsen<br>**Phone**(360) 956-2148 **Fax:** (360) 956-2030 | |
| **Technical Monitor:**<br>Christy Herig<br>**Phone**: 303-384-6546<br>**Fax**: 303-384-6491 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $25,000 | **Cost Share Funding:** |

**Project Objective:** This subcontract is directed towards community partnership development activities for the Million Solar Roofs Initiative (MSRI) implementation. The MSRI plans to install one million solar thermal and photovoltaic installations on US buildings by 2010. The plan is to accomplish this through community partnership teams, which may involve the utility/energy service provider, industry (building/solar), state and local governments and other potential stakeholders. The MSRI community teams will coordinate planning education, business alliances, value analysis and infrastructure development to identify the participation approach which best fits the community needs. This flexible approach to implementation of the MSRI should allow the community teams to create a solar technology commercialization plan of highest value and therefore highest potential for sustainability beyond the initiative.

**Approach/Background:** The Washington States 5,000 Solar rooftops By 2005 has already undertaken aggressive steps towards deploying solar electric systems as outlined in the Background section. They will therefore take the lead in this partnership development project through the following activities.

- Organize a meeting between Washington utilities and the Washington solar industry. This meeting will identify the community partnership team and provide the foundation for the collaborative to obtain the 5,000 solar rooftop goal as committed to the Million Solar Roofs Initiative.

- Utilizing the output from the meeting, develop a consensus document which identifies the collaborative partnership team, the short term commitments to build the infrastructure for solar technology deployment (local and state) and develop the long term plan for the collaborative's participation in the MSR initiative through the year 2010.

**Status/Accomplishments:** The first activity has been completed.

**Planned FY 1999 Milestones:** Many new ideas and initiatives resulted from the first activity. Sorting these out into a plan will complete the final activity.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV Domestic Applications and Markets

# Photovoltaic Technology, Application, and Market Analysis Support

| **Contract #:** CCE-8-18659-01 | **Contract Period:** 4/1/98–7/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Ann Deering, Consultant<br>330 E. 39th St., Ste 34L<br>New York, NY 10016 | |
| | **Organization Type**: | **Congressional District:** 14 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>A. Deering | |
| **Technical Monitor:**<br>J. Thornton<br>**Phone**: 303-384-6469<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $18,000 | **Cost Share Funding:** |

**Project Objective:** The objective is to initiate working discussions on the use of PV for emergency prevention, response and recovery between key executives of the insurance industry and federal agencies, such as DOE and the Federal Emergency Management Agency (FEMA).

**Approach/Background:** The consultant will organize a meeting between DOE, FEMA and insurance industry executives to be held in conjunction with the "Under the Sun" exhibit at the Cooper Hewitt, National Design Museum in New York City. Attendees will discuss various methods for implementing the adoption and use of PV and other renewables by the insurance industry and the general public, including outreach programs.

**Status/Accomplishments:** A meeting was held on June 22, 1998 at the National Design Museum. More than 25 insurance executives attended as well as representatives from DOE, FEMA, NREL, New York City emergency management personnel and local public utilities. A presentation by NREL staff provided an introduction to PV and other renewable applications for use in emergencies. Discussions included case studies of the demonstrated disaster resistance of PV, solar hot water systems, and energy efficient buildings. One of the key strategies to emerge from the meeting was to embark on an expanded outreach program to the public, company officials and local insurance agents.

**Planned FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None. Two issue papers will be published in early FY 1999

## PV Domestic Applications and Markets

# Photovoltaic Technology, Application, and Market Analysis Support

| **Contract #:** AAK-6-16784-1 | **Contract Period:** 6/19/96–12/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | McNeil Technologies, Inc<br>6564 Loisdale Court, S-800<br>Springfield, VA 22150-1872 | |
| | **Organization Type**: IN | **Congressional District:** 8 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>K. DeGroat<br>**Phone:** 703-921-1632 **Fax:** | |
| **Technical Monitor:**<br>R. McConnell<br>**Phone**: 303-384-6419<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1996: $198,145<br>1997: $67,000<br>1998: $93,344 | **Cost Share Funding:** |

**Project Objective:** The project's objective is to provide analytical support relevant to NREL's implementation of PV program activities, technologies, and goals.

**Approach/Background**: Understanding PV markets and the associated applications provides guidance for PV technologies, their R&D, and the PV program.

**Status/Accomplishments:** McNeil analysts examined major trends in PV technologies, their R&D, PV applications, and their markets in order identify areas of strength and weakness in PV development. The analysis included industry and market activities in Japan, Europe, the developing world, as well as state-by-state activities in the US. Identification of major thrusts in the world PV marketplace, such as building-integrated PV in foreign markets and space PV market growth, provides opportunities to leverage related or supporting activities in the program.

**Planned FY 1999 Milestones:** This project will close out with a review and analysis of innovative PV technologies awarded from the 1998 Request for Proposals for University R&D for Future Generation PV Technologies.

**Major Reports Published in FY 1998:**
*NREL Photovoltaic Program FY 1997 Annual Report*, NREL/BK-210-23607, (June 1998).

**Major Articles Published in FY 1998:** None

## PV Domestic Applications and Markets

# Sunrayce 99 Management

| **Contract #:** AAX-8-18646-01 | **Contract Period:** 12/1/97–12/31/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | New Resources Group<br>12 Cedars<br>Freeman, MO 64746 | |
| | **Organization Type**: IN | **Congressional District:** 4 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>D. Eberle<br>**Phone:** 816-899-5511 **Fax:** 816-250-5430 | |
| **Technical Monitor:**<br>B. Stafford<br>**Phone**: 303-384-6426<br>**Fax**: 303-384-6490 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1998: $157,163 | **Cost Share Funding:** |

**Project Objective:** To provide technical support and planning of Sunrayce 99.

**Approach/Background:** Sunrayce 99 is an intercollegiate program for colleges and universities within North America. Students design, build, and race a solar-powered car across part of the United States. The subcontractor will organize and operate Sunrayce Headquarters, which will be the principal contact point for students and the public. The subcontractor will also develop a new race route for Sunrayce 99.

**Status/Accomplishments:** Sunrayce Headquarters began operating at the DOE Atlanta Regional Support Office in April. Previously, it was operated out of the Detroit area. A race route from the Capitol in Washington, DC, to Epcot, near Orlando, Florida, is planned and a solar car test run of the route was done in June 1998.

**Planned FY 1999 Milestones:** Deliver actual route description of proposed route (November 1998).

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV Domestic Applications and Markets

# State PV Models

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| **Contract #:** AU-8436 | **Contract Period:** 10/23/96–9/30/97 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | North Carolina State University<br>Raleigh, NC 27695-7401 | |
| | **Organization Type**: CU | **Congressional District:** 4 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>B. Brooks<br>**Phone:** 917-515-7147 **Fax:** 917-515-5778 | |
| **Technical Monitor:**<br>R. Hill<br>**Phone:** 505-844-6111<br>**Fax:** 505-844-6541 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $19,000<br>1997: $0<br>1998: $0 | **Cost Share Funding:** |

**Project Objective:** Summarize experiences and lessons learned with PV projects at state agencies around the country.

**Approach/Background:** By a survey, a count of the number of systems installed and the experiences gained will be tabulated. An analysis will be performed on this data.

**Status/Accomplishments:** Report has been written. It is accessible on the North Carolina Solar Center web site. It will also be incorporated into a Sandia publication in late 1998.

**FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None

## PV Domestic Applications and Markets

# Renewable Energy Technology Analysis (RETA)

| **Contract #:** FG4194R110639 | **Contract Period:** 5/1/94–12/31/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Pace University Law School<br>78 North Broadway<br>White Plains, NY 10603-3710 | |
| | **Organization Type**: CU | **Congressional District:** 19 |
| **Directing Organization**:<br>Department of Energy, Boston Support Office<br>One Congress Street<br>Boston, MA 02144 | **Principal Investigator (s)**<br>S. Swanson<br>**Phone:** 518-266-1245 **Fax:** 518-283-5008 | |
| **Technical Monitor:**<br>R. Michaud<br>**Phone**: 617-565-9713<br>**Fax**: 617-565-9723 | **B&R Code**: EB22 | **Cost Share Information**:<br>None. |
| | **DOE Funding Allocation:**<br>1994: $180,000<br>1995: $200,000<br>1998: $200,000 | **Cost Share Funding:** |

**Project Objective:** Support consideration of advancing utility investments in Photovoltaics by providing information, education, and training to public interest groups, including environmental and community-based consumer proponents.

**Approach/Background:** Coordinate with the Photovoltaics Compact Coordination Council in order to encourage and support public interest group participation in State Working Group Collaboratives and utility PV installation projects such as TEAM-UP. It also involves coordination with the PVEP Project that is being conducted out of NARUC. This was an unsolicited proposal, DOE No. P9400002C. The proposal was paneled in Boston, recommended for funding, and the Justification for Acceptance of an Unsolicited Proposal was originated and signed by the Program Officer in Boston, Counsel and a Contract Officer in Boston, and forwarded and signed in Washington by the DOE Assistant Secretary, EE, during March and April, 1994.

**Status/Accomplishments:** Provided information, education, and training to public interest groups, including environmental and community-based consumer proponents, regarding the cost effectiveness of utility investments in photovoltaics

**Planned FY 1999 Milestones:** None. Contract is completed under broad-based solicitation.

**Major Reports Published in FY 1998:**
Restructuring: A Regional Perspective, 1997.
Restructuring: An Environmental Status Report, The UPVG Record, 1997.
Restructuring: An Environmental Perspective, 1997.

**Major Articles Published in FY 1998:**
None.

## PV Domestic Applications and Markets

# Photovoltaic Power Systems in the Built Environment

| **Contract #:** AAR-8-18620-01 | **Contract Period:** 2/25/98–9/30/98 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Solar Design Associates<br>Harvard, MA 01451-0242 | |
| | **Organization Type**: IN | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Steven J. Strong<br>**Phone:** 978-456-6855 **Fax:** 978-456-3030 | |
| **Technical Monitor:**<br>S. Hayter<br>**Phone**: 303-384-7519<br>**Fax**: 303-38437540 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $49,232 | **Cost Share Funding:** |

**Project Objective:** The objective of this subcontract was to support representation by the US on the International Energy Agency PV Power Systems Task 7, "Photovoltaic Power Systems in the Built Environment." US involvement with this task leads to a better understanding of international PV in buildings activities and an opportunity for the US to become competitive in the worldwide PV in buildings industry.

**Approach/Background:** The International Energy Agency (lEA) is an organization that promotes the collaborative research, development, and demonstration of new energy technologies between nations. IEA PVPS Task 7, "Photovoltaic Power Systems in the Built Environment," is a 5-year effort involving approximately 15 countries. The objective of the task is to enhance the architectural quality, technical quality, and economic viability of PV systems in the built environment and to assess and remove non-technical barriers for their introduction as an energy-significant option. The US participated in the previous related task, lEA SHC Task 16, "Photovoltaics in Buildings." This task concluded in the spring of 1996. The US has also been involved with lEA PVPS Task 7 since its inception in the fall of 1996.

**Status/Accomplishments:** 1) The US representative to IEA PVPS Task 7 coordinated all the meeting arrangements for the Task 7 members to hold one of their 1998 semi-annual meetings in Orlando, FL. The meeting was held April 29 – May 1, in conjunction with SOLTECH98. 2) The US representative completed requirements for supplying information to fulfill requests by the various Task 7 activity leaders. During FY 98, Task 7 was still in its information gathering stage for all of the actives within the 4 subtask areas. 3) The US representative met with Task 7 members both at Task 7 meetings and met with individual members throughout the year.

**Planned FY 1999 Milestones:** Continue to represent the US on IEA PVPS Task 7 and provide information as needed to the activity leaders.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV Domestic Applications and Markets

# Whole Buildings Design Brochure

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| **Contract #:** ADC-8-18451-01 | **Contract Period:** 8/10/98–5/1/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Solar Design Associates<br>P.O. Box 242<br>Harvard, MA01451 | |
| | **Organization Type**: IN | **Congressional District:** 5 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Steven J. Strong<br>**Phone:** 978-456-6855<br>**Fax :** 978-456-3030 | |
| **Technical Monitor:**<br>S. Craine<br>**Phone**: 303-384-7566<br>**Fax**: 303-384-7540 | **B&R Code**: EB22 | **Cost Share Information**:<br>Exemplary Building Program |
| | **DOE Funding Allocation:**<br>1998: $24,995 | **Cost Share Funding:**<br>1999: $25,000 |

**Project Objective:** The project objective was to create a brochure that defined the "whole-buildings" process, describe integrated building technologies including BIPV, and illustrate how "whole building" design can reduce a buildings energy use. The goal of the brochure is to communicate the message that "whole buildings" or low-energy buildings can be created when the components of a building are integrated properly.

**Approach/Background:** The NREL PV for Buildings Task and the NREL Exemplary Buildings Program equally support the "Whole-Buildings" brochure. The brochure encourages teams of builders, developers, architects, and engineers in the building industry to use the "whole building" process. The "whole building" process prioritizes and incorporates energy efficiency and renewable energy technologies throughout a building's design, construction, commissioning, and operation. The brochure includes individual technology descriptions as well as case studies that show how proper integration of these technologies reduces a buildings energy use.

**Status/Accomplishments:** Research for prospective technologies to be considered for use in the brochure was completed. Potential case studies have been identified to support the definition of the integrated technology and "whole building" design concept. Brochure outline has been developed using the proposed technologies and case studies. Text has been developed describing the technologies to be included in the brochure.

**Planned FY 1999 Milestones:** Case studies will be selected and developed to the level of detail necessary to meet the goals of this publication. The concept layout will include the placement of the integrated technology descriptions, case study descriptions, photos, and other appropriate graphics. A four page summary brochure will be developed for the lay audience to provide a summary overview of whole building design and its benefits. Both the 32 page detailed and four page summary brochures will be delivered as two electronic documents in four color, ready for publication by the government printer.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV Domestic Applications and Markets

# Photovoltaic Development

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| **Agreement#:** DE-FG36-98GO10370 | **Project Period:** 9/30/98–9/29/99 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>D. Ton — **Phone:** 202-586-4618 — **Fax:** 202-586-8148 | Solar Energy Industries Association (SEIA)<br>122 C Street, NW, 4th Floor<br>Washington, DC 20001 | |
| | **Organization Type:** TA | **Congressional District:** AL |
| **Directing Organization:**<br>Golden Field Office<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Victoria Rennie<br>**Phone:** 202-383-2607 **Fax:** 202-383-2670 | |
| **Project Manager:**<br>Robert Martin<br>**Phone:** 303-275-4763<br>**Fax:** 303-275-4753 | **B&R Code:** EB22 | **Cost Share Information:** |
| | **DOE Funding Allocation:**<br>1997: $600,000<br>1998: $300,000 | **Cost Share Funding:** |

**Project Objective:** The objective of the proposed agreement with SEIA involves the furtherance of DOE mission goals through a grant that: 1) promote solar energy markets by disseminating information related to the commercial successes of photovoltaics, solar thermal building and solar thermal electric technologies at a SolTech Conference, 2) provide technical analysis of market barriers that impact roof mounted photovoltaic systems, 3) facilitate technology transfer of specific photovoltaic industry data, and 4) assist local communities and municipalities in developing solar energy projects. The principal activities include the compilation and dissemination of solar energy and photovoltaic information to the public and target groups through conferences and workshops, market research and analysis, publications and community and municipal outreach.

**Approach/Background:** Under this grant, Solar Energy Industries Association (SEIA) intends to develop of solar thermal and photovoltaic technologies. The grant encompasses support for conferences, technical analysis, market promotion and technology transfer in the areas of solar thermal power, photovoltaics and solar thermal buildings.

**Status/Accomplishments:** Through this grant, SEIA promoted the use of solar thermal electric, solar thermal buildings, and photovoltaic products and services through the coordination of the annual conference, exhibition and trade show: SOLTECH '98. The conference will highlighted solar products and services to utilities, architects, engineers, builders, and state, federal, and national energy consumers and suppliers.

**Planned FY 1999 Milestones:** By the end of the grant period, SEIA will compile all the current information on solar products from the industry members and produce and issue two easy-to-use, cross referenced directories; provide a technical analysis of market barriers impeding implementation of roof-based solar systems in the United States, including but not limited to, net metering, interconnectivity standards, and restrictive covenants, prioritize the barriers, and provide case studies concerning the three barriers of greatest significance; and select three community sites for detailed evaluation, for the purpose of installation of and/or micro manufacturing of up to 1MW of solar power.

**Major Reports Published in FY 1998:** none

**Major Articles Published in FY 1998:** none

# PV Domestic Applications and Markets

## Renewable Energy and Energy Efficiency Technologies in Building Codes and Standards

| **Contract #:** AAA-8-18450-01 | **Contract Period:** 6/15/98–9/15/98 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Managers:**<br>R. King — **Phone:** 202-586-1693 — **Fax:** 202-586-8148<br>J. Mazer — **Phone:** 202-586-2455 — **Fax:** 202-586-8148 | Wortman Engineering<br>9767 Oxford Rd.<br>Longmont, CO 80501 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>Dave Wortman<br>**Phone:** 303-652-2118 **Fax:** 303-652-2118 | |
| **Technical Monitor:**<br>S. Hayter<br>**Phone**: 303-384-7519<br>**Fax**: 303-384-7540 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $34,314 | **Cost Share Funding:** |

**Project Objective:** This subcontract completed the following activities. A) Identify issues in existing and proposed building codes and standards that affect implementation of energy efficiency and renewable energy technologies in buildings. B) Provide information that addresses these issues in a way that is acceptable to code officials and code writing bodies. C) Provide input and recommendations as to how these codes and standards should be revised where necessary. D) Provide supporting analysis and data as required by code officials and code producing bodies.

**Approach/Background:** The Center for Buildings and Thermal Systems at the National Renewable Energy Laboratory (NREL) in collaboration with industry develops renewable energy (RE) and energy efficient (EE) technologies for application in buildings. Renewable energy and energy-efficient technologies often do not fit neatly into existing building codes and standards. As a result, code officials are often not comfortable accepting RE and advanced EE technologies integrated into buildings, or the RE and advanced EE strategies are not given credit for reducing building energy consumption for energy code compliance. The purpose of this contract was to help eliminate barriers to the application of RE and EE technologies in building codes and standards. Approximately half the effort applied in this subcontract was to address photovoltaic (PV) in building systems with the balance applied to other EE and RE technologies.

**Status/Accomplishments:** The subcontractor completed a detailed report for NREL internal use. The report focuse on how current residential building codes address PV in building systems and other EE and RE technologies.

**Planned FY 1999 Milestones:** NREL PV for Buildings staff plans to publish an NREL document that focuses on findings related to PV and solar domestic hot water system that were included in the draft that the subcontractor completed in FY98. It is not anticipated that the subcontractor will continue work on this activity with NREL.

**Major Reports Published in FY 1998:**
*N/A*

**Major Articles Published in FY 1998:**
*N/A*

## PV for International Applications

# Mexico Support

| **Contract #:** BB-5930 | **Contract Period:** 2/27/98–2/26/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Arizona Public Service Co.<br>400 N. 5th St.<br>Phoenix, AZ 85004-3902 | |
| | **Organization Type**: IN | **Congressional District:** 2 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>C. V. Mathai<br>**Phone:** 602-250-3569 **Fax:** 602-250-3872 | |
| **Technical Monitor:**<br>C. Hanley<br>**Phone:** 505-844-4435<br>**Fax:** 505-844-7786 | **B&R Code**: EB22 | **Cost Share Information**:<br>DOE/Wind<br>DOE/Storage<br>USAID/Mexico |
| | **DOE Funding Allocation:**<br>1998: $50,000 | **Cost Share Funding:**<br>$50,000<br>$50,000<br>$100,000 |

**Project Objective:** Implementation of renewable energy hybrid mini-grid in Baja California Sur, Mexico, to increase the use of renewable energy technologies in Mexico. This program is supported by both DOE and USAID/Mexico. (Total contract is $250,000, with $50,000 applicable to photovoltaics.)

**Approach/Background:** Support implementation of a centralized hybrid wind-PV-diesel mini-grid system in the village of San Juanico. This pilot project will provide valuable knowledge and expertise regarding the use of hybrid renewable energy systems, which expertise will be applicable to future projects in Mexico.

**Status/Accomplishments:** APS has received all DOE contributions. Equipment has been ordered and construction is underway.

**FY 1999 Milestones:** Completion of installation of project.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

## PV for International Applications

## Renewable Energy Business Development in China

| **Contract#:** AAX-8-17679-01 | **Contract Period:** 2/26/98–2/25/99 |
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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Center for Renewable Energy Development<br>Zhansimen Road, Shahe, Changping County<br>Beijing 102206, P.R.C. | |
| | **Organization Type:** ZZ | **Congressional District:** |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>J. Li<br>**Phone:** 011 8610 6973-7074 **Fax:** 011 8610 6973-3110 | |
| **Technical Monitor:**<br>W. Wallace<br>**Phone:** 303/384-6476<br>**Fax:** 303/384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1997: $94,933<br>1998: $39,870 | **Cost Share Funding:** |

**Project Objective:** To establish a framework for specific collaboration in order to promote renewable energy business development between the U.S. and China. To support the development of an extensive information base consisting of business related data from the US and China for mutual exchange with companies in both countries. To proactively support the development of renewable energy projects in China and project participation by U.S. and Chinese companies.

**Approach/Background:** Joint cooperation with the Center for Renewable Energy Development in Beijing is conducted to generate a number of information products to exchange between China and the U.S. for the purpose of promoting business cooperation and the development of opportunities. Joint efforts are also conducted to generate financing for renewable energy projects in China. Technical assistance is also provided to support policy development in China and provide services as a clearinghouse for information transfer.

**Status/Accomplishments:** Several information exchange projects were initiated and completed. A business information tour was conducted by Scott Vaupen for four provinces in China to extend a previous 10 province study. This tour was supported by the Center for Renewable Energy Development. A U.S. business consultant was also supported to conduct an assessment of the PV industry in China. Over 25 companies in China were interviewed, business opportunities and interests were identified, and PV markets and applications in China were characterized. A technology status report is also being prepared for PV in China.

**Planned FY 1999 Milestones:** Several reports are in a final editing stage and will be published in early 1999.

## PV for International Applications

# Rural Electrification Using Photovoltaics in Northwestern China

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| **Contract#:** AAX-8-17680-01 | **Contract Period:** 12/5/97–6/4/99 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Chinese Ministry of Agriculture<br>No. 11 Nongzhanguan Nanli<br>Beijing 100026, P.R.C. | |
| | **Organization Type:** ZZ | **Congressional District:** |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>J. Li<br>**Phone:** 011 86 10 6419-2610 **Fax:** 011 86 10 6500-2448 | |
| **Technical Monitor:**<br>W. Wallace<br>**Phone:** 303/384-6476<br>**Fax:** 303/384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>Chinese Ministry of Agriculture |
| | **DOE Funding Allocation:**<br>1996: $100,000 1998: $50,000 | **Cost Share Funding:**<br>1996: $80,000 |

**Project Objective:** In general, there are several objectives. To expand the use of PV renewable energy systems throughout western and northwestern China for solar home lighting, educational school systems, etc. by expanding the knowledge base for solar applications in rural China, especially through the Gansu Project. To perform technical and economic analysis for rural electrification options to identify the most cost effective way on a life cycle basis for supplying rural electrification needs in China. To characterize the market for solar rural electrification systems in Qinghai and Xinjiang provinces in western China. To provide technical assistance for a regional testing and training facility being supported by the Ministry of Agriculture in Lanzhou in China.

**Approach/Background:** Rural electrification options analyses will be conducted on data which has been collected in surveys for Xinjiang and Qinghai provinces in northwestern China. The analyses will characterize the best options for supplying rural electrification needs in this remote region of China and will provide a characterization of the existing market for solar PV systems. Technical assistance will be supplied to the regional testing and training facility in Lanzhou to support the resources of the Chinese Ministry of Agriculture in extending the training services available to several provinces in western China and in providing adequate test facilities to assess quality of solar home system components and systems being installed in this region of China.

**Status/Accomplishments:** Surveys at the county level in ten counties in Xinjiang and Qinghai and the required provincial and national data has been collected and sent to the U.S. in the joint analysis project. Technical assistance on an ongoing basis is being provided to the Lanzhou regional facility. A major Workshop on Small PV/Wind Technology Applications for Rural and Remote Development in China in Beijing in September of 1998 with the participation of over 25 Chinese and 10 U.S. companies.

**Planned FY 1999 Milestones:** Publish analysis results of the project.

**Major Articles Published in FY 1998:**

"PV Electrification in India and China: The NREL's Experience in International Cooperation," J. Stone, Y. Tsuo, H. Ullal, W. Wallace, E. Sastry, and B. Li, *Prog. Photovolt. Res. Appl.*, **6**, 341-356 (1998).

## PV for International Applications

# Mexico Support

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| **Contract #:** AV-1215 | **Contract Period:** 12/6/96–9/30/99 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Ecoturismo y NT<br>Zaragosa, Mexico | |
| | **Organization Type**: ZZ | **Congressional District:** |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Arturo Romero | |
| **Technical Monitor:**<br>C. Hanley<br>**Phone:** 505-844-4435<br>**Fax:** 505-844-7786 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1996: $95,000 | **Cost Share Funding:** |

**Project Objective:** Provide technical and strategic support to the Mexico Renewable Energy Program, specifically activities in Quintana Roo, Baja California Sur, and in protected areas.

**Approach/Background:** Provides technical support for pilot renewable energy projects with partner organizations in Mexico.

**Status/Accomplishments:** Project implementation/training activities proceeding on schedule.

**FY 1999 Milestones:**
Establishment of a local committee in Quintana Roo to oversee implementation of renewable energy projects.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:**
R. Foster, A. Romero, et al. "USAID/DOE Mexico Renewable Energy Program: Building Foundations for Growing Markets."
A. Romero, SWRES, et al. "Sistema Hibrido Eolico Diesel para Aplicacion Ecoturistica."
A. Romero, R. Foster, et al. "Resumen de Cinco Anos de Operacion del Sistema Hibrido de X-Calak."

## PV for International Applications

# Mexico Renewable Energy Assessment

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| **Contract #:** AX-1916 | **Contract Period:** 9/15/97–6/30/99 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | KPMG<br>P.O. Box 3939<br>Albuquerque, NM 87190- | |
| | **Organization Type**: ZZ | **Congressional District:** 1 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Brian Barnett<br>**Phone:** 505-884-3939 **Fax:** 505-880-3873 | |
| **Technical Monitor:**<br>C. Hanley<br>**Phone:** 505-844-4435<br>**Fax:** 505-844-7786 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1997: $38,000<br>1998: $6,000 | **Cost Share Funding:** |

**Project Objective:** Perform an assessment of the potential market for renewable energy technologies in Mexico in several sectors.

**Approach/Background:** KPMG is to utilize their international business capabilities to investigate the potential for applications of renewable energy technologies in several productive-use applications in Mexico.

**Status/Accomplishments:** Report completed, then updated with newly-available data. Report has been distributed to sponsors and interested stakeholders.

**FY 1999 Milestones:** None.

**Major Reports Published in FY 1998:** "Market Guidebook of Renewable Energy Applications in Mexico"

**Major Articles Published in FY 1998:** None.

## PV for International Applications

# Mexico Support

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| **Contract #:** BB-4655 | **Contract Period:** 12/5/97–12/4/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Photocomm, Inc.<br>7812 E. Acoma Dr.<br>Scottsdale, AZ 85260-6978 | |
| | **Organization Type**: IN | **Congressional District:** 4 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>Ron Kenedi<br>**Phone:** 602-951-6330 **Fax:** 602-951-6329 | |
| **Technical Monitor:**<br>C. Hanley<br>**Phone:** 505-844-4435<br>**Fax:** 505-844-7786 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $10,000 | **Cost Share Funding:** |

**Project Objective:** Provide technical and strategic support to the Mexico Renewable Energy Program.

**Approach/Background:** Provides technical support for pilot renewable energy projects with partner organizations in Mexico.

**Status/Accomplishments:** Training of Potential distributors and renewable energy engineers in two Mexican states has led to significant growth in sales for Golden Genesis (formerly Photocomm).

**FY 1999 Milestones:** None. Contract ends in December.

**Major Reports Published in FY 1998:** None.

**Major Articles Published in FY 1998:** None.

# U.S./China Progress Report on the Protocol for Cooperation in the Fields of Energy Efficiency and Renewable Energy Technology Development and Utilization

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| **Contract#:** AAA-8-18689-01 | **Contract Period**: 8/11/98–11/15/98 |

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| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Princeton Economic Research, Inc.<br>1700 Rockville Pike, Suite 550<br>Rockville, MD 20852 | |
| | **Organization Type:** IN | **Congressional District**: 8 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Daniel Ancona<br>**Phone:** 301-881-0650 **Fax:** 301-230-1232 | |
| **Technical Monitor:**<br>W. Wallace<br>**Phone:** 303/384-6476<br>**Fax:** 303/384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1998: $60,000 | **Cost Share Funding:** |

**Project Objective:** The objective of this subcontract was to prepare a progress report for work done under the U.S./China Protocol for Cooperation in the Fields of Energy Efficiency and Renewable Energy Technology Development and Utilization. In addition, the subcontractor provided support for the First Working Group Meeting for this protocol conducted in Washington, D.C. in November 1998.

**Approach/Background:** The Princeton Economic Research, Inc. coordinated the collection of information from the six annexes under the Energy Efficiency and Renewable Energy Protocol and prepared a draft report covering the past three years of work performed for the Protocol. The report is in the process of final editing with annex coordinators on the U.S. and China sides. PERI also provided logistical support for the Protocol Working Group Meeting conducted in Washington, D.C. during November 1998.

**Status/Accomplishments:** The Protocol Report is in the process of final editing and will be published in early 1999.

**Planned FY 1999 Milestones:** Report publication.

**Major Reports Published in FY 1998:**
*Progress Report: United States and People's Republic of China Cooperation in the Field of Energy Efficiency and Renewable Energy,* to be published in early 1999.

**Major Articles Published in FY 1998:**

## PV for International Applications

# China PV Business and Application Evaluation

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|---|---|
| **Contract#:** AAA-8-18688-01 | **Contract Period**: 8/7/98–10/31/98 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Sherring Energy Associates<br>3 Bellaire Drive<br>Princeton, N.J. 08540-7824 | |
| | **Organization Type:** IN | **Congressional District:** 12 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Chris Sherring<br>**Phone:** 609-799-8889 **Fax:** 609-799-5258 | |
| **Technical Monitor:**<br>W. Wallace<br>**Phone:** 303/384-6476<br>**Fax:** 303/384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1998: $57,490 | **Cost Share Funding:** |

**Project Objective:** The project consultant reviewed all sectors of the PV industry, applications, and market segments in China in order to collect extensive relevant information of use and benefit to the U.S. renewable energy industry and other interested parties. The consultant worked in close cooperation with the Center for Renewable Energy Development in Beijing and received assistance from that organization. A report is being edited for printing and distribution to the U.S. PV industry.

**Approach/Background:** A consultant from the U.S. PV business community was funded to perform an extensive review of all sectors of the Chinese PV. Interviews were conducted at over 25 companies in China in seven provinces to generate detailed information related to the company's position in the PV industry in China, its business activities, and potential interests in working with U.S. companies. The companies included PV module manufacturers, system integrators, distributors, balance-of-system component manufacturers, and others. Observations and information was collected on all PV market sectors in China and an evaluation was conducted for the potential for PV market development. Other organizations contacted included research institutes and government agencies that support PV development in China.

**Status/Accomplishments:** The information from over 25 companies and additional organizations characterizing in depth the current status of PV development in China was collected and analyzed. This information, conclusions generated from assessments, identification of PV business opportunities in China, and recommendations for business development were assimilated in a report which will be distributed to U.S. industry.

**Planned FY 1999 Milestones:** Report publication.

**Major Reports Published in FY 1998:**
*CHINA PV Business & Application Evaluation,* Chris Sherring, in editing, to be published in FY 1999.

**Major Articles Published in FY 1998:**

# Photovoltaics for Rural Energy in Gansu Province in the People's Republic of China

| | |
|---|---|
| **Contract#:** AAX-6-15376-01 | **Contract Period:** 12/19/95–2/28/99 |

| | | |
|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Solar Electric Light Fund<br>Suite 595<br>1775 K Street, N.W.<br>Washington, D.C. 20006 | |
| | **Organization Type:** NP | **Congressional District:** AL |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>R. Freling<br>**Phone:** 202-234-7265 **Fax:** 202-328-9512 | |
| **Technical Monitor:**<br>W. Wallace<br>**Phone:** 303/384-6476<br>**Fax:** 303/384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>Solar Electric Light Fund |
| | **DOE Funding Allocation:**<br>1995: $120,000 1998: $60,000<br>1996: $100,000 | **Cost Share Funding:**<br>1996: $220,000 |

**Project Objective:** The Solar Electric Light Fund has participated in the development of a viable commercial infrastructure for the successful deployment of PV systems for rural energy development in Gansu Province. In prior years over 300 remote household PV lighting systems and 10 school systems have been installed in several villages in Gansu. These installations have been installed using declining subsidies over time and leveraging through the use of a revolving account, which uses revenues from system sales to finance more system installations.

**Approach/Background:** The Solar Electric Light Fund has worked with the Gansu Solar Electric Light Fund (GSELF) in Lanzhou. GSELF is supported by the Gansu Poverty Alleviation Office, the Gansu State Economic and Trade Commission, and the Gansu State Planning Commission. The organization performs several functions, including working with county rural energy offices to market solar home systems, contracting with companies to purchase and install systems, and manage the financing of systems. Three Chinese companies in Gansu supply equipment and install systems for the project, and four U.S. companies have participated in the project by supplying equipment.

**Status/Accomplishments:** Over 300 systems have been installed in Gansu. An ongoing training project for engineers, village technicians, and market personnel has been established. The project has supported the formation of a distribution network for system sales. U.S. companies have been inserted into the marketplace for PV rural electrification systems in western China and experience has been gained with U.S. products in the field, establishing their superior quality over available domestic components. Opportunities for further business development for U.S. companies have been identified. A field survey of the currently installed systems in the Gansu project has been conducted after several months of operation.

**Planned FY 1999 Milestones:** Complete the Gansu project and perform the final field survey and assessment of the project.

**Major Articles Published in FY 1998:**
*The Use of Photovoltaics for Rural Electrification in Northwestern China,* W. Wallace, J. Li, and S. Gao, Proc. of the 2nd World Conference and Exhibition on Photovoltaic Solar Energy conversion, 6-10 July 1998, Vienna, Austria.

## PV for International Applications

# SWRES Mexico Support

| **Contract #:** AT-7335 | **Contract Period:** 6/4/96–9/30/99 |
|---|---|

| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Southwest Technology Development Institute (SWTDI)<br>Las Cruces, NM 88003-0001 | |
| | **Organization Type**: ST | **Congressional District:** 2 |
| **Directing Organization**:<br>Sandia National Laboratories, Albuquerque<br>P.O. Box 5800, MS0753<br>Albuquerque, NM 87185-0753 | **Principal Investigator (s)**<br>R. Foster<br>**Phone:** 505-646-3948 **Fax:** 505-646-3841 | |
| **Technical Monitor:**<br>C. Hanley<br>**Phone:** 505-844-4435<br>**Fax:** 505-844-7786 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1998: $300,000 | **Cost Share Funding:** |

**Project Objective:** Provide technical and strategic support to the Mexico Renewable Energy Program.

**Approach/Background:** Provides technical support for pilot renewable energy projects with partner organizations in Mexico.

**Status/Accomplishments:** Pilot photovoltaic systems installed in four Mexican states during each quarter of FY98. Installed system database, completed and updated quarterly, with accompanying geographic information system. Spanish-language guidebook to implementation of PV water pumping systems completed. At least three major training activities were conducted with support from this contract.

**FY 1999 Milestones:** Support to program milestones: pilot installations in 12 Mexican states (50% increase in states); report on programmatic impacts; continued maintenance of database and web page.

**Major Reports Published in FY 1998:** "Guia para el Desarrollo de Proyectos de Bombeo de Agua con Energia Renovable," FIRCO and Sandia National Laboratories.

**Major Articles Published in FY 1998:**
R. Foster, et al. "Willingness to Pay for Photovoltaic Systems in Rural Chihuahua, Mexico."
R. Foster, et al. "USAID/DOE Mexico Renewable Energy Program: Building Foundations for Growing Markets."
R. Foster, et al. "Life-Cycle Cost Analysis for Photovoltaic Water Pumping Systems in Mexico."
R. Foster, et al. "Resultados del Programa de Energia Fotovoltaica para Bombeo de Agua en Chihuahua."
SWRES, et al. "Sistema Hibrido Eolico Diesel para Aplicacion Ecoturistica."
R. Foster, et al. "Resumen de Cinco Anos de Operacion del Sistema Hibrido de X-Calak."
R. Foster, et al. "Photovoltaic Generation System Acceptance Tests for the Montes Azules Integrated Biosphere Reserve: Chajul Biological Station, Campamento Chajul, Campamento Ixcan: Chiapas, Mexico."

## PV for International Applications

# Evaluation of SPV Systems Installed under INDO-US Collaboration Programme, Sundarbans, West Bengal

| | |
|---|---|
| **Contract #:** AAD-6-16780-01 | **Contract Period:** 7/18/96 – 3/31/98 |

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|---|---|---|
| **Sponsoring Office Code:** EE-11 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Tata Energy and Resources Institute<br>1600 Wilson Boulevard<br>Arlington, VA 22209 | |
| | **Organization Type**: NP | **Congressional District:** 11 |
| **Directing Organization**:<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator (s)**<br>P. Venkat Ramana<br>**Phone:** 703-841-1136 **Fax:** 703-243-1865 | |
| **Technical Monitor:**<br>J. Stone<br>**Phone**: 303-384-6470<br>**Fax**: 303-384-6481 | **B&R Code**: EB22 | **Cost Share Information**:<br>None |
| | **DOE Funding Allocation:**<br>1994: $0 1997: $0<br>1995: $0 1998: $0<br>1996: $38,974 | **Cost Share Funding:** |

**Project Objective:** To evaluate the social and economic impacts of PV systems on the end users in the remote Sundarbans region of West Bengal, India.. The systems were installed under the auspices of the joint INDO-US collaborative rural electrification initiative.

**Approach/Background:** The subcontractor did an onsite evaluation through interviews and inspections of a representative group from the 300 beneficiaries in eight villages in the Sundarbans region. The principal application was home lighting for which the impacts on education and entertainment as well as cost factors were evaluated. Other areas impacted included improvements in medical facilities, improved productivity in a weaving station, and improved community relations in various youth clubs and gathering places. Several battery charging stations were installed allowing locals to improve their lot by charging for the service.

**Status/Accomplishments:** The project was successfully completed and a final report was issued. The applications were readily accepted by the end users and the economics compared to the fossil fuel alternatives are favorable. The project was extended to two thousand other beneficiaries through purchases by other villagers.

**Planned FY 1999 Milestones:** Plans are to revisit the area after about one year of operational experience and to repeat the study.

**Major Reports Published in FY 1998:**
Final report submitted by subcontractor, not published.

**Major Articles Published in FY 1998:**
Paper presented at the Second World Photovoltaic Conference held in Vienna, Austria.

# Evaluation of Intermediate Applications for Photovoltaics in the United States and Developing Countries

| | |
|---|---|
| **Contract#:** XCU-7-16806-01 | **Contract Period:** 6/1/97–1/31/99 |

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|---|---|---|
| **Sponsoring Office Code:** EE-13 | **Performing Organization(s)** | |
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | University of Delaware<br>Center for Energy and Environmental Policy<br>Newark, DE 19716 | |
| | **Organization Type:** CU | **Congressional District:** AL |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>J. Byrne<br>**Phone:** 301-831-8405 **Fax:** 302-831-3098 | |
| **Technical Monitor:**<br>W. Wallace<br>**Phone:** 303/384-6476<br>**Fax:** 303/384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None. |
| | **DOE Funding Allocation:**<br>1996: $125,000<br>1998: $ 22,575 | **Cost Share Funding:** |

**Project Objective:** In FY 1998, the project focus has been on completing a rural electrification survey and analysis project in China.

**Approach/Background:** In FY 1998, the subcontractor collaborated with the Chinese Ministry of Agriculture and the Chinese Ministry of Sciences to collect data and perform analyses from a technical and socio-economic survey of several counties in Inner Mongolia, Xinjiang, and Qinghai provinces in China. Analyses consisted of evaluating rural electrification options and performing market characterizations for the northwestern region of China. Start text here

**Status/Accomplishments:** Data templates were prepared by the University of Delaware for data collection in 20 counties in three provinces in northwestern China under the supervision of the Ministry of Agriculture and the Chinese Academy of Sciences in China. The information was transmitted in Excel spreadsheet format to University of Delaware for analysis. Currently, a stage two data collection process is in progress to fill gaps in the first data set and preliminary analyses are being conducted , scheduled for completion during the first quarter of FY 1999.

**Planned FY 1999 Milestones:** Publish the results of the rural electrification survey and analysis.

**Major Reports Published in FY 1998:**

**Major Articles Published in FY 1998:**
"The Economics of Sustainable Energy for Rural Development: A Study of Renewable Energy in Rural China," John Byrne, Bo Shen, and William Wallace, *Energy Policy,* Vol. 1, No. 26, pp. 45-54, 1998.

## PV for International Applications

# Renewable Energy Business Development in China

| **Contract#:** AAX-8-18676-01 | **Contract Period:** 6/10/98–10/10/98 |
|---|---|

| **Sponsoring Office Code:** EE-13 | **Performing Organization(s)** | |
|---|---|---|
| **DOE HQ Program Manager:**<br>R. King<br>**Phone:** 202-586-1693<br>**Fax:** 202-586-8148 | Xinergy Resources<br>3122 9th Road North #3<br>Arlington, VA 22201 | |
| | **Organization Type:** IN | **Congressional District:** 8 |
| **Directing Organization:**<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401 | **Principal Investigator(s)**<br>Scott Vaupen<br>**Phone:** 202-303-2501 **Fax:** 202-303-2505 | |
| **Technical Monitor:**<br>W. Wallace<br>**Phone:** 303/384-6476<br>**Fax:** 303/384-6490 | **B&R Code:** EB22 | **Cost Share Information:**<br>None |
| | **DOE Funding Allocation:**<br>1998: $18,000 | **Cost Share Funding:** |

**Project Objective:** This project was designed to support the U.S. renewable energy industry in developing business opportunities in China. The objectives included collecting information on a province specific basis, assimilating the information into a report, and distributing the report to the U.S. industry.

**Approach/Background:** Information was collected that included: I) specific project information, especially for projects open for international competition, ii) information on the general business environment in a given province, including regulatory, policy, market information, etc., iii) summaries of Chinese companies and other business groups that are interested in doing business with U.S. companies, and iv) prospects for specific technologies in a given province. This assessment is an extension of a previous report done in 1997, which analyzed six provinces including Inner Mongolia, Gansu, Shandong, Qinghai, Xinjiang, and Zhejiang.

**Status/Accomplishments:** An information survey was conducted in China in four additional provinces as an extension of the 1997 report. The four provinces surveyed included Guangdong, Jiangxi, Jilin, and Yunnan. The report details the legal, competitive, social-cultural, technological, geographic, and economic environments in these provinces. In addition, it outlines the major Central government policies and contacts important to renewable energy development in China.

**Planned FY 1999 Milestones:** The report will be published in early FY 1999 after final editing.

**Major Reports Published in FY 1998:**
*Renewable Energy Markets in China: An Analysis of Renewable Energy Markets in Guangdong, Jiangxi, Jilin, and Yunnan with Updated Information from Beijing,* Scott Vaupen, in editing, to be published in early 1999.

**Major Articles Published in FY 1998:**

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# ORGANIZATION CODES

**CU** College, University, or Trade School (Non-HBCU)
**HB** Historically Black College or University
**FF** Federally Funded (R&D Lab Operated for Profit
**IN** Private Industry
**NP** Foundation or Lab (Non-Profit)
**ST** Regional, State, or Local Government Facility
**TA** Trade or Professional Organization
**US** Federal Agency
**ZZ** Foreign

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